06

CLIMATE
CHANGE
RESEARCH
REPORT
CCRR-06

Climate Change and Ontario's Provincial Parks:

Towards an Adaptation Strategy

Responding to Climate Change Through Partnership

Ontario

Climate Change and MNR: A Program-Level Strategy and Action Plan

The following describes how the Ministry of Natural Resources works to contribute to the Ontario Government's commitment to reduce the rate of global warming and the impacts associated with climate change. The framework contains strategies and sub-strategies organized according to the need to understand climate change, mitigate the impacts of rapid climate change, and help Ontarians adapt to climate change:

Theme 1: Understand Climate Change

Strategy #1: Gather and use knowledge in support of informed decision-making about climate change. Data and information gathering and management programs (e.g., research, inventory, monitoring, and assessment) that advances our knowledge of ecospheric function and related factors and forces such as climate change are critical to informed decision-making. Accordingly, MNR will work to:

- Strategy 1.A: Develop a provincial capability to describe, predict, and assess the important short- (0-5 years), medium- (5-20 years), and long-term (20+ years) impacts of climate change on the province's ecosystems and natural resources.
- Strategy 1.B: Model the carbon cycle.

Strategy #2: Use meaningful spatial and temporal frameworks to manage for climate change. A meaningful spatial and temporal context in which to manage human activity in the ecosphere and address climate change issues requires that MNR continue to define and describe Ontario's ecosystems in-space and time. In addition, MNR will use the administrative and thematic spatial units required to manage climate change issues.

Theme 2: Mitigate the Impacts of Climate Change

Strategy #3: Gather information about natural and cultural heritage values and ensure that this knowledge is used as part of the decision-making process established to manage for climate change impacts. MNR will continue to subscribe to a rational philosophy and corresponding suite of societal values that equip natural resource managers to take effective action in combating global warming and to help Ontarians adapt to the impacts of climate change.

Strategy #4: Use partnership to marshal a coordinated response to climate change. A comprehensive climate change program involves all sectors of society as partners and participants in decision-making processes. The Ministry of Natural Resources will work to ensure that its clients and partners are engaged.

Strategy #5: Ensure corporate culture and function work in support of efforts to combat rapid climate change. Institutional culture and function provide a "place" for natural resource managers to develop and/or sponsor proactive and integrated programs. The Ministry of Natural Resources will continue to provide a "home place" for the people engaged in the management of climate change issues.

Strategy #6: Establish on-site management programs designed to plan ecologically, manage carbon sinks, reduce greenhouse gas emissions, and develop tools and techniques that help mitigate the impacts of rapid climate change. On-site land use planning and management techniques must be designed to protect the ecological and social pieces, patterns, and processes. Accordingly, MNR will work to:

- Strategy 6.A: Plan ecologically.
- Strategy 6.B: Manage carbon sinks.
- Strategy 6.C: Reduce emissions.
- Strategy 6.D: Develop tools and techniques to mitigate the impacts of rapid climate change.

Theme 3: Help Ontarians Adapt

Strategy #7: Think and plan strategically to prepare for natural disasters and develop and implement adaptation strategies. MNR will sponsor strategic thinking and planning to identify, establish, and modify short- and long-term direction on a regular basis. Accordingly, MNR will work to:

- Strategy 7.A: Sponsor strategic management of climate change issues.
- Strategy 7.B: Maintain and enhance an emergency response capability.
- Strategy 7.C: Develop and implement adaptation strategies for water management and wetlands.
- Strategy 7.D: Develop and implement adaptation strategies for human health.
- Strategy 7.E: Develop and implement adaptation strategies for ecosystem health, including biodiversity.
- Strategy 7.F: Develop and implement adaptation strategies for parks and protected areas for natural resource-related recreational opportunities and activities that are pursued outside of parks and protected areas.
- Strategy 7.G: Develop and implement adaptation strategies for forested ecosystems.

Strategy #8: Ensure policy and legislation respond to climate change challenges. Policy, legislation, and regulation guide development and use of the programs needed to combat climate change. MNR will work to ensure that its policies are proactive, balanced and realistic, and responsive to changing societal values and environmental conditions.

Strategy #9: Communicate. Ontarians must understand global warming, climate change, and the known and potential impacts in order to effectively and consistently participate in management programs and decision-making processes. Knowledge dissemination through life-long learning opportunities that are accessible and current is critical to this requirement. MNR will raise public understanding and awareness of climate change through education, extension, and training programs.

Climate Change and Ontario's Provincial Parks:

Towards an Adaptation Strategy

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2007

Ontario

University of Waterloo

Applied Research and Development Branch • Ontario Ministry of Natural Resources

Library and Archives Canada Cataloguing in Publication Data

Main entry under title:
Climate change and Ontario's provincial parks : towards an adaptation strategy

(Climate change research report ; CCRR-06)
Includes bibliographical references.
Available also on the Internet.
ISBN 978-1-4249-3394-5

1. Climatic changes—Ontario.
2. Climatic changes—Ontario—Forecasting.
3. Provincial parks and reserves—Environmental aspects—Ontario.
4. Ecosystem management—Ontario.
I. Lemieux, Christopher J., 1977- .
II. Ontario. Ministry of Natural Resources. Applied Research and Development.
III. Series.

QC981.8 C5 C54 2007 551.69713 C2007-964000-1

Printed in Ontario, Canada

Single copies of this publication
are available from:

Applied Research and Development
Ontario Forest Research Institute
Ministry of Natural Resources
1235 Queen Street East
Sault Ste. Marie, ON
Canada P6A 2E5

Telephone: (705) 946-2981
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Cette publication hautement spécialisée *Climate Change and Ontario's Provincial Parks: Towards an Adaptation Strategy* n'est disponible qu'en anglais en vertu du Règlement 411/97, qui en exempte l'application de la *Loi sur les services en français*. Pour obtenir de l'aide en français, veuillez communiquer avec le ministère de Richesses naturelles au information.ofri@ontario.ca.

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Summary

This report assesses the implications of climate change for Ontario's system of provincial parks. A broad range of climate change impacts (e.g., changes in ecosystem composition, structure, and function as well as increased forest fire severity) were identified as potentially significant for Ontario Parks' policy, planning, and management frameworks. While the literature review and the models described in this report identify a number of potential impacts resulting from climate change (e.g., changes in biome climate envelope representation, increased forest fire severity, and the loss of polar bear [*Ursus maritimus*] habitat from Polar Bear Provincial Park), significant knowledge gaps remain in many areas. As such, the results presented in this study should be taken as *indicative*, not predictive, of the magnitude of impact climate change may have on Ontario's provincial parks.

A historical climate regime was completed for a representative sample of eight provincial parks to illustrate variability and trends in mean annual temperature (MAT) and total annual precipitation (TAP) during the 20th and early 21st centuries. While statistical significance varied, MAT increased at all stations over their respective historical records compared to the 1961 to 1990 period. TAP increased in all but Lake Superior Provincial Park over the historical record when compared to the 1961 to 1990 period.

Using some of the climate change scenarios sponsored by the Intergovernmental Panel on Climate Change (IPCC), changes in temperature and precipitation are projected for the sample of parks for the periods 2020 to 2029, 2050 to 2059, and 2080 to 2089. Based on the outputs from the scenarios, most parks are projected to experience MAT increases of 1.8 to 3.2°C in the 2020s, 1.8 to 7.0°C in the 2050s, and 2.5°C to 10.0°C in the 2080s. The greatest increases in temperature are projected for the more northern parks, including Tidewater Provincial Park in the northeast and Wabakimi Provincial Park in the northwest. The majority of scenarios project an increase in TAP. There is, however, considerable variability in the projected changes to the minimum and maximum temperature and precipitation between the parks analyzed, times considered (e.g., 2020s, 2050s, and 2080s), and the scenarios evaluated.

Using global circulation model (GCM)-driven global vegetation models (GVMs), this analysis projected changes to the climate envelope of biome types (i.e., climatic requirements) in Ontario provincial parks. Results indicate that 64 to 93% of Ontario's provincial parks could experience a change in biome climate envelope during the 21st century. The climate envelopes of more northerly biomes are projected to retreat further north and the taiga biome climate envelope is projected to shift north beyond the political boundary of Ontario altogether. The climate envelopes for the more southerly biomes, including temperate and savanna forest climate envelopes, are projected to advance north as well.

Finally, using a Canadian General Circulation Model (CGCM2)-driven fire model, we present historical and projected changes in fire severity (the potential for increased forest fire intensity and a longer forest fire season) for Ontario's system of provincial parks for the 2050s (doubled-CO_2) and 2090s (tripled-CO_2) compared to the baseline period of 1980 to 1989. In general, results showed declines in the *low* forest fire severity rankings and a significant increase in *high* and *extreme* forest fire severity rankings by the 2050s and 2090s. For example, during the 1980 to 1989 baseline period, only 3% of Ontario's provincial parks were classified within the *extreme* fire severity ranking. By the 2050s, this percentage increases to 10% and by the 2090s, *extreme* fire severity is projected to expand into nearly a quarter (21%) of all provincial parks.

Based on published impact studies and the models described in this report, provincial park policies, system planning, and park objectives appear to be sensitive to climate change. The implications are described and observations and suggestions relevant to the current planning and management frameworks of Ontario Parks are presented.

Résumé

Le changement climatique et les parcs provinciaux de l'Ontario : vers une stratégie d'adaptation

Dans ce rapport, on évalue les incidences du changement climatique sur le réseau de parcs provinciaux de l'Ontario. On estime qu'une vaste gamme de répercussions attribuables au changement climatique (p. ex., modifications dans la composition, la structure et la fonction des écosystèmes et gravité accrue des incendies de forêts) seront éventuellement importantes en ce qui a trait aux cadres d'action, de planification et de gestion des parcs de l'Ontario. Bien que l'analyse documentaire et les modèles décrits dans le rapport relèvent de nombreux effets du changement climatique [p. ex., changements dans la représentation de l'enveloppe climatique des biomes, gravité accrue des incendies de forêts et destruction des habitats de l'ours blanc (*Ursus maritimus*) dans le parc provincial Polar Bear], les données demeurent nettement incomplètes pour un grand nombre de domaines. Les résultats présentés dans cette étude constituent donc des *indicateurs*, et non pas des prédictions, de l'ampleur des incidences possibles du changement climatique sur les parcs provinciaux de l'Ontario.

Le régime climatique historique d'un échantillon représentatif de huit parcs provinciaux a été établi pour faire ressortir la variabilité et les tendances de la température moyenne annuelle (TMA) et de la précipitation totale annuelle (PTA) au cours du XX^{e} et au début du XXI^{e} siècle. Bien que la signification statistique ait varié, la TMA indiquée sur les dossiers historiques de chacune des stations a augmenté à toutes les stations par rapport à la période de 1961 à 1990. Selon la comparaison de ces données historiques et de celles de la période de 1961 à 1990, les précipitations totales annuelles (PTA) ont augmenté dans tous les parcs à l'exception du parc provincial du Lac Supérieur.

Au moyen de certains scénarios portant sur le changement climatique cautionnés par le Groupe d'experts intergouvernemental sur l'évolution du climat (GEIÉC), on a projeté des changements de température et de précipitations dans les parcs faisant l'objet de l'étude pour les périodes de 2020 à 2029, de 2050 à 2059 et de 2080 à 2089. D'après les résultats obtenus, la plupart des parcs devrait connaître des hausses de la TMA de 1,8 à 3,2 °C durant les années 2020, de 1,8 à 7,0 °C durant les années 2050 et de 2,5 à 10,0 °C durant les années 2080. Les plus importantes hausses de température devraient être observées dans les parcs les plus au nord, notamment le parc provincial Tidewater, situé dans le nord-est de l'Ontario, et le parc provincial Wabakimi, dans le nord-ouest de la province. D'après les résultats de la majorité des scénarios, on prévoit une augmentation de la PTA. Toutefois, les changements projetés de la température et des précipitations minimales et maximales varient considérablement entre les parcs analysés selon les périodes retenues (c.-à-d. les années 2020, 2050 et 2080) et les scénarios évalués.

Grâce à l'utilisation du modèle de végétation dynamique (MVD) fondé sur le modèle de circulation générale (MCG), cette analyse prévoit des changements de l'enveloppe climatique (c.-à-d. les conditions climatiques essentielles) de certains types de biomes présents dans les parcs provinciaux de l'Ontario. Les résultats révèlent qu'au XXI^{e} siècle, un changement de l'enveloppe climatique des biomes pourrait se produire dans 64 à 93 % des parcs provinciaux de l'Ontario. On prévoit que l'enveloppe climatique des biomes les plus septentrionaux se déplacera encore plus vers le nord et que celle de la taïga se déplacera vers le nord et franchira tout à fait la limite territoriale de l'Ontario. Les enveloppes climatiques des biomes plus méridionaux, y compris celles de la forêt tempérée et de la savane boisée, devraient aussi se déplacer vers le nord.

Enfin, à l'aide d'un modèle d'incendie reposant sur le modèle canadien de circulation générale (CGCM2), on examine les changements historiques et projetés de la gravité des incendies de forêts (risque d'augmentation de l'intensité des incendies et de prolongation de la saison des incendies) dans le réseau des parcs provinciaux de l'Ontario durant les années 2050 (où les concentrations de CO_2 doubleront) et 2090 (où les concentrations de CO_2 tripleront) par rapport à la période de référence de 1980 à 1989. En général, les résultats démontrent que les *faibles* indices de gravité des incendies *diminueront* et que les indices *modérés* et *élevés* augmenteront de façon marquée d'ici les années 2050 et les années 2090. Par exemple, pendant la période de référence de 1980 à 1989, l'indice *extrême* de gravité d'incendie n'est attribué qu'à 3 % des parcs provinciaux de l'Ontario. Selon le modèle, ce pourcentage passera à 10 % d'ici les années 2050 et l'indice *extrême* de gravité s'étendra dans presque le quart (21 %) de tous les parcs provinciaux d'ici les années 2090.

D'après les rapports de recherches publiés relativement aux conséquences du changement climatique et aux résultats des études effectuées à l'aide des modèles présentées dans ce rapport, les politiques en matière de parcs provinciaux, de planification du réseau et d'objectifs propres aux parcs semblent être sensibles à ce phénomène. Les préoccupations que suscite le changement climatique sont décrites et un certain nombre de recommandations stratégiques visant le cadre actuel de planification et de gestion des parcs de l'Ontario sont formulées.

Acknowledgements

This research was completed under the auspices of the Ontario Ministry of Natural Resources (OMNR) Climate Change Project (CC-03/04 and CC-04/05). We thank Bob Davidson and Barton Feilders for their interest and support of this research. We thank Lisa Buse and Trudy Vaittinen for editing and formatting this report. Gratitude is also extended to the Social Sciences and Humanities Research Council (SSHRC) for additional financial support.

The authors extend gratitude to the authors of Neilson (1995), Haxeltine and Prentice (1996), and Malcolm and Markham (2000) for access to Global Vegetation Model (GVM) results. We thank Brian Stocks for providing the climate change fire severity models used in this analysis. We thank the Canadian Council on Ecological Areas (CCEA) for providing access to the Canadian Conservation Areas Database (CCAD). Monique Kuyvenhoven is owed many thanks for providing protected areas data. Help provided by Scott Kaufman in the historical climate trend analysis is greatly appreciated. We thank Steve Colombo and Burke Korol for their valuable comments on an earlier version of the manuscript.

Finally, Gordon Nelson of the Parks Research Forum of Ontario (PRFO) is owed special thanks for the opportunity to conduct the research and for access to resources at the University of Waterloo.

Acronyms Used in this Report

ANSI	Area of Natural and Scientific Interest
CCAD	Canadian Conservation Areas Database
CCEA	Canadian Council on Ecological Areas
CCELC	Canada Committee on Ecological Land Classification
CCIS	Canadian Climate Impacts and Scenarios
CCME	Canadian Council of Ministers of the Environment
CCRS98	Japanese Centre for Climate System Research General Circulation Model
CGCM1	Canadian General Circulation Model, First Generation
CGCM2	Canadian General Circulation Model, Second Generation
CSIRvOMK26	Australian Commonwealth Scientific and Industrial Research Organization General Circulation Model
DGVM	Dynamic Global Vegetation Model
FAR	Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report
GCM	Global Circulation Model
GFDL	Geophysical Fluid Dynamics Laboratory
GHG	Greenhouse Gas
GIS	Geographic Information System
GISS	Goddard Institute of Space Studies Global Circulation Model
GVM	Global Vegetation Model
HadCM2	Hadley Centre Global Circulation Model, Second Generation
IBP	United Nations International Biological Programme
IJC	International Joint Commission
IPCC	Intergovernmental Panel on Climate Change
MAPSS	Mapped Atmosphere-Plant-Soil System
MAT	Mean Annual Temperature
MPI	Max Planck Institute for Meteorology Global Circulation Model
NRCAN	Natural Resources Canada
OMNR	Ontario Ministry of Natural Resources
PCIC	Pacific Climate Impacts Consortium
PRFO	Parks Research Forum of Ontario
RMRs	Required Migration Rates
SAR	Intergovernmental Panel on Climate Change (IPCC) Second Assessment Report
SRES	IPCC Special Report on Emission Scenarios
TAP	Total Annual Precipitation
UKMO	United Kingdom Meteorological Office Global Circulation Model
UN	United Nations
UNCBD	United Nations Convention on Biological Diversity
UNFCCC	United Nations Framework Convention on Climate Change

Contents

Introduction

The international scientific community asserts that rising concentrations of greenhouse gases (GHGs) in the Earth's atmosphere, resulting from anthropogenic activities occurring since the onset of the industrial revolution, are contributing to a change in climate around the world. The Intergovernmental Panel on Climate Change (IPCC) is the leading international organization providing scientific input in support of the *United Nations Framework Convention on Climate Change* and the *Kyoto Protocol*. The Working Group I contribution to the IPCC *Fourth Assessment Report* (FAR) estimates that temperatures have increased 0.74ºC over the past century alone, with countries located in more northern latitudes warming more than those located closer to the equator (IPCC 2007). In Canada, temperatures have increased approximately 1.3°C since the mid-1950s, substantially greater than the global average increase (Environment Canada 2007). The IPCC *FAR* projects that global annual mean temperatures will increase by 1.1 to 6.4ºC by 2100 (IPCC 2007) and a review by Pittock (2006) suggests that the probability of exceeding 3ºC has increased in recent years.

Due to a number of interacting factors, including reduced period of snow cover and associated loss of albedo, reduced ice cover, and warmer oceanic temperatures, greater climatic change is expected at northern latitudes. For example, 32 warm-start coupled General Circulation Model (GCM) experiments project mean annual temperature increases of 2.7 to 11.5ºC by the 2080s in the central interior of Canada and 4.2 to 12.9ºC in the Canadian arctic (PCIC 2006). In Ontario, these GCM simulations suggest an increase in mean annual temperature between 0.7 and 3.1ºC for the 2020s, 1.9 and 6.9ºC for the 2050s, and 2.7 and 10.6ºC for the 2080s (PCIC 2006). These projections are substantially higher than the global average increase of 1.1 to 6.4ºC projected by the IPCC (2007).

Given the magnitude of these climate change projections and because this change may occur over a relatively short period of time (i.e., decades), global climate change is possibly the most significant environmental issue facing Earth's ecosystems and the people who depend on them in the 21st century. Since the initial scientific assessment conducted by the IPCC (IPCC 1990), 185 nations have ratified the *United Nations Framework Convention on Climate Change* (UNFCCC). In addition, a number of countries, including Canada, have ratified the *Kyoto Protocol* which came into effect on February 18, 2005.

Global biodiversity likely will be significantly affected by climate change. According to Holdridge (1947), Woodward (1987), and Bailey (1996), the distribution of terrestrial ecosystems is primarily determined by climate, particularly temperature and precipitation. Already experiencing stresses from habitat destruction, fragmentation, pollution, and over-exploitation, natural systems will need to adapt rapidly to new climate regimes or they will disappear and be replaced by new and different ecosystems.

The implications of climate change for ecosystem composition, structure, and function (including biodiversity) in Ontario are considerable. For example, many protected areas have been established to protect specific plant and animal species and communities *in-situ* and have not been designed to account for climate-induced changes to ecosystem composition, structure, and function. Every species will respond to climate change in unique ways based on life cycle and ecophysiological requirements. In the absence of physical barriers, some species will migrate significant distances. However, in some cases, natural (e.g., lakes) or human-made barriers (e.g., urban and agricultural areas) will impede species movement. As a result, some parks and protected areas in Ontario may become unsuitable for some of the species they now support, but able to support new and/or invasive species currently using niches in other locations.

The anticipated changes in ecosystems in response to climate change, coupled with some species' inability to phenotypically and/or genetically adapt to new climatic conditions or migrate to suitable climatic zones, could hinder the ability of protected area managers and planners to maintain some habitats and species populations (Peters and Darling 1985, Peters and Lovejoy 1992, Halpin 1997, Scott *et al.* 2002, Hannah *et al.* 2005). Thomas

et al. (2004: 147) have even stated that *"Despite the uncertainties… the overall conclusions … establish that anthropogenic climate warming at least ranks alongside other recognized threats to global biodiversity [and] contrary to previous projections, it is likely to be the greatest threat in many if not most regions."* A recent report by the World Wildlife Fund (WWF 2003: 1) similarly emphasized that "…*protected areas offer a limited defense against problems posed by rapid environmental change [and] protected areas will themselves need to be changed and adapted if they are to meet the challenges posed by global warming."* Scott *et al.* (2002), Hannah *et al.* (2002), and Scott and Lemieux (2005) suggest that climate change has the potential to undermine more than a century of conservation efforts.

In general, research on the impacts of climate change for conservation management in protected areas has been limited and completed mostly outside of the agencies and organizations responsible for the management of protected areas (Scott *et al.* 2002). These knowledge gaps limit short- and long-term policy, planning and management responses, including adaptation, to climate change. In fact, most protected area agencies in Canada have not begun to consider the implications of climate change to policy, planning, and management frameworks, let alone develop adaptation strategies (Lemieux *et al.* in prep). This report was prepared to assist parks and protected areas managers in Ontario and around the world in their work to address the complex and dynamic impacts of climate change.

Goals and Objectives

In collaboration with Ontario Parks and other programs in the Ontario Ministry of Natural Resources (OMNR), the Parks Research Forum of Ontario (PRFO), and the University of Waterloo, a scoping assessment of the impacts of climate change in Ontario's system of provincial parks is presented. The goals of this assessment are to (1) examine the potential implications of climate change for ecosystems in Ontario's system of provincial parks and (2) explore the potential implications these changes may have for protected area policy, planning, and management in Ontario.

To achieve these goals, this assessment:

(1) Qualitatively assesses how climate change is expected to impact some abiotic features, species, ecosystems, and visitor activities in Ontario's system of provincial parks.

(2) Assesses temperature and precipitation variability and trends using historical climate records for eight Ontario provincial parks.

(3) Projects some future climate (temperature and precipitation) regimes for the 2020s, 2050s, and 2080s for a sample of Ontario provincial parks.

(4) Describes potential changes to the climate envelope of vegetation biomes in some of Ontario's provincial parks using global climate models in conjunction with global vegetation models.

(5) Projects potential fire severity change in Ontario's system of provincial parks using a GCM-driven fire model.

(6) Begins to explore the positive, neutral, and negative impacts of climate change on the current Ontario Parks system planning and individual park management plans (including the goals and objectives of these plans).

(7) Identifies gaps in our understanding of climate change impacts on Ontario's provincial parks.

(8) Provides observations, suggestions, and direction for future research.

Secondary objectives of this assessment are to:

(1) Improve understanding of how geographic information system (GIS) modelling can be used to examine the potential impacts of climate change on Ontario's provincial parks.

(2) Identify the limitations of climate change and GIS modelling for protected areas.

(3) Provide a methodology which can be replicated to complete climate change analyses in future projects.

This assessment represents an initial step in support of the development of a strategic and adaptive response to the impacts of climate change by Ontario Parks and the OMNR.

OMNR's Strategic Plan for Responding to Climate Change

The research presented in this report responds to the OMNR's program-level strategic plan for managing the impacts of climate change (OMNR 2006), which has three primary goals (or themes):

Theme 1: Understand Climate Change

Research that falls within this theme provides an important and necessary scoping assessment of the potential impacts of climate change on Ontario's system of provincial parks. It highlights recent climate trends and projected changes in climate and the vegetation-climate envelope in a representative sample of Ontario's provincial parks. Given that little research has been completed on the potential impacts of climate change to the Ontario provincial parks system, the results presented here will assist park managers in their efforts to integrate climate change into protected area policy, planning, and management.

Theme 2: Mitigate the Impacts of Climate Change

For protected area managers to respond effectively to the challenges and opportunities resulting from climate change, understanding ecosystem-climate relationships and climate change impacts is key. Research in this theme provides scenarios (potential "pictures of the future") to help park managers ask "what if" questions and to develop mitigation tools and techniques to protect natural heritage values where possible.

Theme 3: Help Ontarians Adapt

The research presented in this report supports the OMNR's objectives to encourage strategic thinking and planning to identify, establish, and modify short and long-term direction related to climate change and protected areas planning, policy, and management. It also provides observations and suggestions designed to assist staff in their efforts to formulate a framework for managing the impacts of climate change. From a provincial parks perspective, for example, this research will assist in addressing:

1) Issues arising from climate-induced changes to the distribution and abundance of species.

2) Issues related to park boundaries.

3) Changing recreational opportunities.

4) Education and training program needs.

Methods

This assessment examines the potential impacts of climate change on Ontario's system of provincial parks in five steps:

Step 1: Literature Review

The literature review synthesizes climate change-related research that is relevant to or conducted in Ontario's provincial parks. Specifically, the review outlines the implications of climate change for biodiversity, ecosystem function, and social and economic values.

Step 2: Historical Climate Analysis and Climate Change Projections for Ontario's Provincial Parks

2a) Historical Variability and Trend Analysis

We constructed historical climate data sets from a sample of climate stations near provincial parks in five of the six Ontario Parks administrative zones (Fig. 1 and Table 1).[1] The objective was to illustrate recent climatic (i.e., temperature and precipitation) trends and variability (based on differences from the 1961 to 1990 baseline climate) in these parks over the historic record and to test these trends for statistical significance. Even though availability of continuous climatic data was important in park and station selection, some data were missing (Appendix 1). Table 2 describes the location, period of record, and source for each climate station used in the analysis.

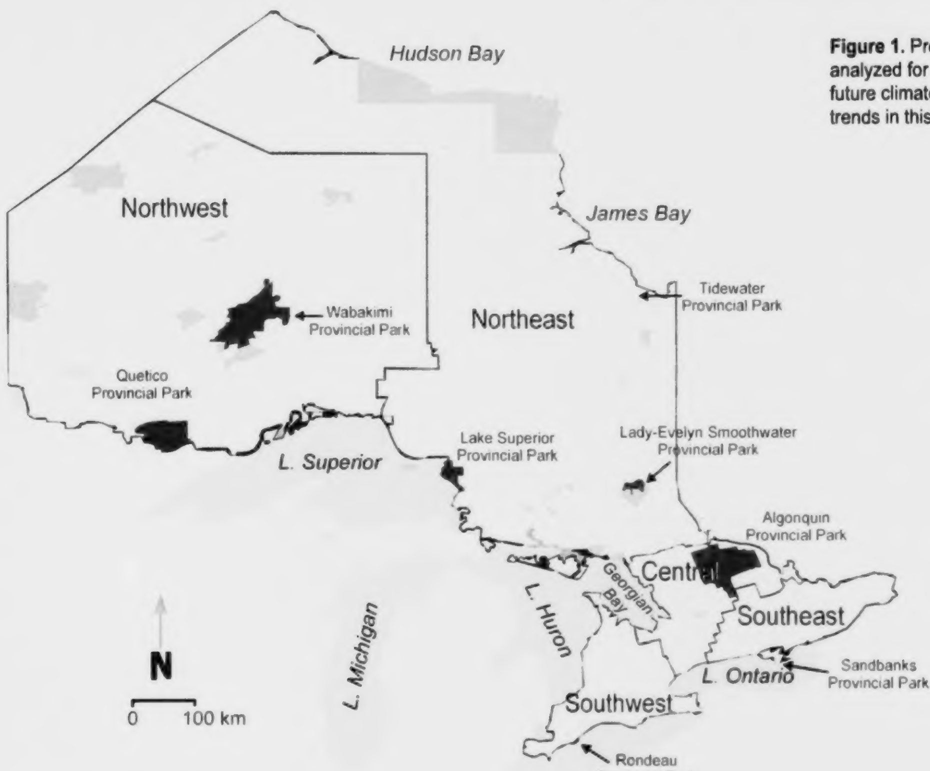


Figure 1. Provincial parks analyzed for historical and future climate variability and trends in this assessment.

[1] Unfortunately, no suitable (i.e., long-term, continuous) climate data were available for provincial parks located in the central zone.

Table 1. Summary of provincial parks analyzed for historical and future climate variability and trends in this study.

Park	Park Class	Size (ha)
Rondeau Provincial Park	Natural Environment[1]	3,254
Algonquin Provincial Park	Natural Environment[1]	765,345
Sandbanks Provincial Park	Natural Environment[1]	1,509
Lady Evelyn-Smoothwater Provincial Park	Wilderness[2]	72,400
Quetico Provincial Park	Wilderness[2]	475,782
Wabakimi Provincial Park	Wilderness[2]	892,061
Lake Superior Provincial Park	Natural Environment[1]	155,646
Tidewater Provincial Park	Natural Environment[1]	980

[1] The objectives of natural environment class parks are to protect outstanding recreational landscapes, representative ecosystems and provincially significant elements of Ontario's natural and cultural heritage and to provide high quality recreational and educational experiences (Government of Ontario 2006).

[2] The objective of wilderness class parks is to protect large areas where the forces of nature can exist freely and visitors travel by non-mechanized means, except as may be permitted by regulation, while engaging in low-impact recreation to experience solitude, challenge and integration with nature (Government of Ontario 2006).

In the south and central part of the province, parks used in this study included Rondeau (Southwest Zone), Algonquin (Algonquin Zone), and Sandbanks provincial parks (Southeast Zone) (Table 1). Due to the vast geographic area and climatic variations in the Northeast and Northwest Zones, additional parks were chosen from each of these zones to illustrate climatic trends over the historical record. These parks included Quetico and Wabakimi provincial parks in the Northwest Zone and Lake Superior, Lady Evelyn-Smoothwater, and Tidewater provincial parks in the Northeast Zone. Results reported here are presented in a format consistent with Hamilton *et al.* (2001), who examined historic climate trends in several Canadian biosphere reserves

Monthly values of mean temperature and total precipitation were acquired for each station from the Environment Canada Historical Adjusted Climate Database (Environment Canada 2006a) of homogenized and long-term temperature time series, which has been specifically designed for climate change analyses. The shortest historical record used for the temperature trend and variability analysis was 64 years for Lake Superior Provincial Park (Wawa A Station) and the longest historical record was 109 years for Quetico (Thunder Bay A Station) and Tidewater (Moosonee Station) provincial parks. The shortest historical record used for the precipitation trend and variability analysis was 57 years (Haliburton Station, one of three stations used for Algonquin Provincial Park) and the longest historical record was 97 years for Quetico Provincial Park (Thunder Bay A Station). A *Kendall Tau* statistical significance test was administered to each data set to determine if the trend was real or simply due to chance.

No climate stations were located within the boundaries of the parks evaluated in this study. For those parks where climate records do exist, the data are fragmented (e.g., climate data for a station located within Algonquin Provincial Park does not extend past 1972) and not suitable for climate trend analyses.

While geographically close, it is important to note that temperature and precipitation measurements collected from sites adjacent to the parks may not be exactly the same as those inside the parks. Additional information on how the Environment Canada (2006a) climate data were constructed and methodological limitations of these data can be found in Vincent (1998), Vincent and Gullet (1999), and Vincent *et al.* (2002).

Table 2. Climate stations used to generate historical climate change trend analysis. More information on how the Environment Canada (2006a) climate data base was constructed can be found in Vincent (1998), Vincent and Gullet (1999) and Vincent *et al.* (2002).

Station[a]	ID[b]	Elev. (m)	Location	Data Type[c]	Record*
Rondeau Provincial Park (Southwest Zone)					
Ridgetown ACS (adj)	6137149	206	42°27'N 81°53'W	T[1]‡, P[2]‡	[1]1923-2002 [2]1924-1996
Algonquin Provincial Park (Algonquin Zone)					
North Bay A (adj)	6085700	370	46°37'N 79°42'W	T[1], P[2]‡	[1]1939-2004 [2]1925-2004
Haliburton 3 (adj)	6163171	330	45°03'N 78°53'W	T‡	1895-2004
Lady Evelyn-Smoothwater Provincial Park (Northeast Zone)					
Earlton A (adj)	6072225	243	47°70'N 79°85'W	T[1], P[2]	[1]1938-2003 [2]1939-2003
Sandbanks Provincial Park (Southeast Zone)					
Belleville (adj)	6150689	76	44°09'N 77°24'W	T	1921-2004
Quetico Provincial Park (Northwest Zone)					
Thunder Bay A (adj)	6048261	199	48°37'N 89°33'W	T[1]‡, P[2]‡	[1]1895-2004 [2]1895-1992
Mine Centre (adj)	6025203	343	48°77'N 92°62'W	T	1915-2004
Fort Frances A (adj)	6022476	342	48°65'N 93°43'W	T‡	1912-2004
Wabakimi Provincial Park (Northwest Zone)					
Sioux Lookout A (adj)	6037775	390	50°12'N 91°90'W	T[1]‡, P[2]‡	[1]1930-2004 [2]1914-2004
Lake Superior Provincial Park (Northeast Zone)					
Wawa A (adj)	6059D09	287	47°97'N 84°78'W	T[1]‡, P[2]‡	[1]1940-2004 [2]1916-2004
Tidewater Provincial Park (Northeast Zone)					
Moosonee (adj)	6075425	10	51°27'N 80°65'W	T‡	1895-2004

a=Station: (adj - adjusted) indicates homogenous data, b=Environment Canada weather station code, c=Data type: T – Mean Annual Temperature; P – Total Annual Precipitation , ‡=joined record (to create long-term series), Data Source: Environment Canada (2006a)

2b) Projections of Future Climates in Ontario

We developed a summary of projected temperature and precipitation changes for a representative sample of provincial parks for the 2020s, 2050s, and 2080s. Consistent with the IPCC recommendation to "*...apply multiple scenarios in impact assessments, where these scenarios span a range of possible future climates, rather than designing and applying a single 'best guess' scenario"* (IPCC 2001), Step 2 describes a range of projected temperature and precipitation changes in a sample of Ontario provincial parks.

We selected a number of different emission scenarios to represent the full range of scenarios described in the *Special Report on Emissions Scenarios (SRES)* (IPCC 2000) and made available by the Pacific Climate Impacts Consortium (PCIC) (2006). The IPCC *SRES* contains four storylines (scenario families) that qualitatively describe the causes of GHG emissions that result from human behaviour (e.g., political, social, cultural and educational conditions). The *SRES* emission scenarios are the quantitative interpretations of these storylines. Forty scenarios were developed by commissioned modelling teams where no single scenario was treated as more or less probable than the others in the same scenario family. In order to reduce the number of scenarios for use in climate change studies, six marker, or illustrative, scenarios were selected by consensus of the IPCC modelling teams. These are the A1FI, A1T and A1B scenarios from the A1 family, and a model representing each of the A2, B1 and B2 families. The A1 and A2 families have a more economic focus than B1 and B2 families, which are more environmentally oriented. In addition, the A1 and B1 families are more global compared to the more regional A2 and B2 families (Fig. 2). The range of potential global average temperatures resulting from modelled scenarios is presented in Fig. 3.

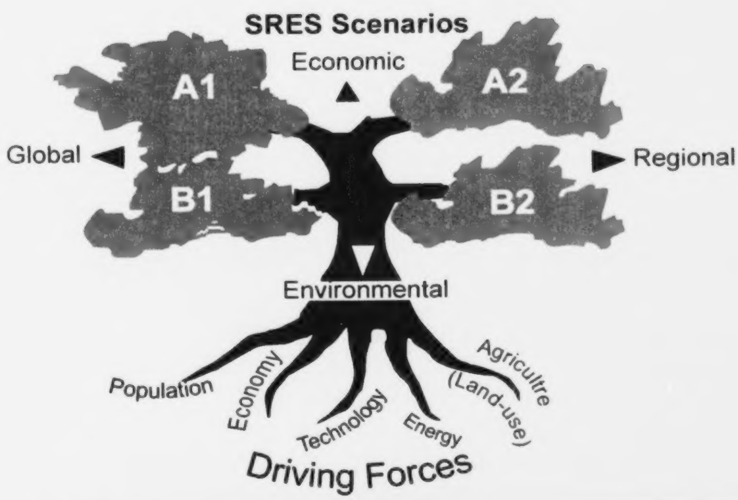


Figure 2. A schematic representation of the SRES (Special Report on Emission Scenarios) scenario family (IPCC 2001).

SRES Scenario	General Attributes
A1	• Population peaks mid-century, then declines • Rapid introduction of new technology and heavily industrialized • A1 groups are distinguished by technological emphasis [fossil intensive (A1F1), non-fossil energy sources (A1T), or a balance of the two (A1B)]
A2	• Continuously increasing population • Slow economic growth and technological solutions • Regional solutions to economic, social, and environmental sustainability
B1	• Population peaks mid-century, then declines • Rapid change in economic structure toward service and information economy and rapid introduction of clean and resource efficient technologies • Global solutions to economic, social, and environmental sustainability
B2	• Continuously increasing population • Less rapid and more diverse technological change • Local solutions to economic, social and environmental sustainability

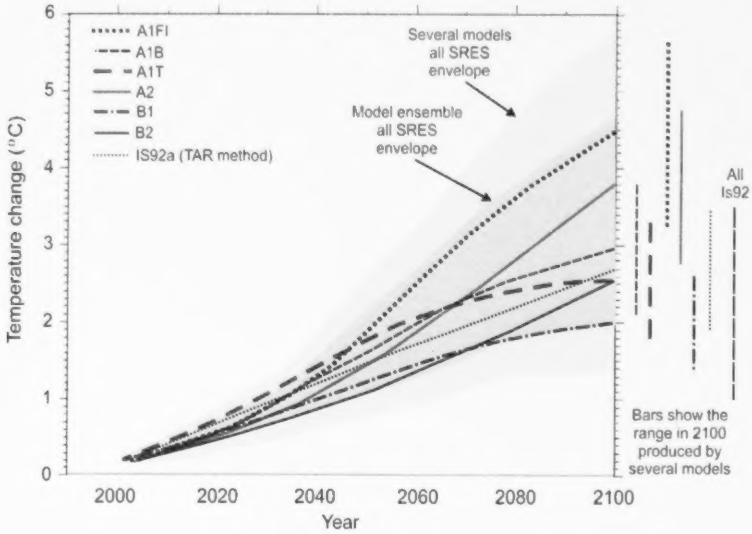


Figure 3. Global-mean temperature change (°C) associated with the six SRES (Special Report on Emission Scenarios) marker scenarios, A1FI, A1T, A1B, A2, B1, B2 and the range of original IS92 scenarios (IPCC 2001).

The quantitative inputs for each scenario include, but are not limited to, measures of population, economic development and energy efficiency, the availability of various forms of energy, agricultural production, and local pollution controls. Explicit policies to limit greenhouse gas emissions or to adapt to the expected global climate change are not included. Additional information about the *SRES* scenarios can be found in IPCC (2001) and scenario data can be accessed at the Canadian Climate Impacts and Scenarios (CCIS) website (http://www.cics.uvic.ca/scenarios/) and the Pacific Climate Impacts Consortium (PCIC) website (http://pacificclimate.org/scenarios/index.php?id=1).

For comparative purposes, the same provincial parks used in the historical climate trend analysis in Step 2a were used to model potential future climate. Provincial park geocentroids (latitude and longitude coordinates) were used to illustrate projected changes in temperature and precipitation for the 2020s, 2050s, and 2080s. These time periods correspond to the 30-year mean periods 2010 to 2039, 2040 to 2069, and 2070 to 2099 and all changes are with respect to the 1961 to 1990 mean period (1970s). Values (geocentroids) outside the limits of a grid cell were rounded to the nearest value within the available grid window. Geocentroid data were obtained from the Canadian Conservation Areas Database (CCAD) (2003) maintained by Natural Resources Canada (NRCAN) and the Canadian Council on Ecological Areas (CCEA).

Given the assumptions that are inherent in the construction of GCMs, a number of limitations are common in many climate models, including an incomplete scientific understanding of how the climate system responds to potentially important physical, chemical, and biological processes and limitations arising from computer resource constraints (including incomplete or inaccurate representations of climate-affecting processes and large grid scale). Even the most current GCMs suffer from coarse spatial and temporal resolution. This coarse resolution limited our ability to project regional-scale impacts of climate change and fire severity (see Step 4). Because of these uncertainties, analyses using transient regional climate models (RCMs) (which were not available at the time of our analysis) are required to address future fire impacts in a more site-specific manner.[2]

The term "scenarios" has been specificially defined to avoid confusion with "predictions". Predictions suggest a degree of certainty whereas scenarios depend on assumptions about future socio-economic conditions and a range of future climate conditions that may evolve. All in all, scenarios help us understand the uncertainty and to plan for the future. In future analyses, RCMs should be used to project future climatic trends for Ontario provincial

[2] For more information on the Hadley Centre Regional Climate Modelling System (PRECIS), which is currently being refined, please refer to: http://precis.metoffice.com/.

parks. RCMs, currently under development, with much higher spatial resolution will permit more accurate regional-scale climate projections. In so doing, the confidence in climate change impact projections will increase.

Results presented here should be taken as *indicative*, not predictive, of the magnitude of impact climate change may have for Ontario's system of provincial parks. Despite these limitations, GCMs are considered to be the only credible tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations (IPCC 2001, PCIC 2006).

Step 3: Terrestrial Vegetation Change Modelling Analysis

We assessed potential climatic envelope changes for biomes in which Ontario's provincial parks are located using two Global Vegetation Models (GVMs): MAPSS (Neilson 1998) and BIOME 3 (Haxeltine and Prentice 1996). GVMs project changes in "vegetation climate" (i.e., the climatic conditions required for certain vegetation types to survive) and are used here as an indicator of potential future vegetation "representation change" in Ontario's provincial parks in response to climate change.

Both MAPSS and BIOME3 are equilibrium process-based models that simulate the potential distribution of generalized types of natural vegetation on the basis of the physiological properties of plants, average seasonal climate, and hydrological conditions. Equilibrium GVMs do not simulate the transitional response of vegetation to climate change, but rather depict vegetation distribution patterns once vegetation has stabilized under changed climate conditions.

A comparison of BIOME2 (a precursor to BIOME3) and MAPSS over the conterminous United States (VEMAP Members 1995) determined that these models simulated current vegetation patterns with approximately equal success. Neilson (1998) found that BIOME2 and MAPSS performed similarly under current climate conditions, although each was better calibrated to their 'home' continents (Europe and North America, respectively). Compared to BIOME2, MAPSS was consistently more sensitive to water stress and elevated CO_2, producing drier future outcomes (VEMAP Members 1995). This difference between the models occurs over many of the drier parts of the world. In this analysis of Ontario's provincial parks, the discrepancies are minor because the few drier vegetation classifications are limited to a small area in Alberta and Saskatchewan. Further, through incorporation of the direct, physiological effect of increased CO_2 levels, MAPSS produced a larger benefit to vegetation from increased water-use-efficiency (WUE) than BIOME2 (Neilson 1998). A concise comparison of the vegetation classification system and eco-physiological processes modelled by MAPSS and BIOME3 is provided in Peng (2000).

Generally, BIOME2 and MAPSS projected a decrease in the size of the tundra ecosystem climate envelope by 30 to 65% under doubled-CO_2 conditions (approximately 2050s). All scenarios also projected that the taiga/tundra climate envelope will decrease in area. In the MAPSS model, the boreal forest climate envelope expanded 8 to 33% under all scenarios (Neilson 1998). In the BIOME3 model, however, the IPCC-Working Group 2 (Neilson 1998) included the taiga/tundra biome in the boreal conifer forest biome, and therefore the BIOME3 simulates a net decrease in the size of the boreal forest climate envelope.

An equilibrium doubled-CO_2 GCM model from the IPCC *First Assessment Report* (FAR) (IPCC 1990: UKMO) and a transient GCM model from the IPCC *Second Assessment Report* (SAR) (IPCC 1996: HadCM2-ghg) were used in the analysis to project change under the GVMs. The climate change scenarios and interpolation procedures (to a 0.5° latitude-longitude resolution) are described in Neilson (1998). Table 3 provides a summary of the projected global temperature changes for GCM experiments used in this assessment.

In general, the transient GCMs used in the IPCC vegetation modelling analysis (Neilson 1998) project less climate change than other GCMs in the IPCC *SAR* (1996). The GCM comparison in Table 3 illustrates that the global climate change projected by the HadCM2 scenario used in this analysis is conservative relative to

Table 3: A comparison of projected global temperature changes determined by General Circulation Models (GCMs)

Model	Characteristics	Projected Warming (°C)		Source
Climate Change Models Used in this Analysis				
UKMO	E, ghg	5.2°C†		IPCC, 1996 - WG I, Sec. 6
HadCM2	T, ga	1.7°C†		IPCC, 1996, WG I, Sec. 6
Other Examples of Climate Change Models (Not Used in this Analysis)				
		Canada §	Global	Source
CGCM1	T, ga *	3.8°C ‡	5.6°C ‡	CCIS, 2002
HadCM2	T, ga *	2.5°C ‡	3.7°C ‡	CCIS, 2002
CCRS98	T, ga	na	6.8°C ‡	CCIS, 2002
CSIRvOMk2b	T, ga	2.7°C ‡	4.9°C ‡	CCIS, 2002

E = Equilibrium, T = Transient, ghg = includes the forcing of greenhouse gases only, ga = includes the forcing of greenhouse gases and atmospheric aerosols, na = data not available, * = ensemble average (consists of a number of climate change scenarios undertaken with identical forcing scenarios, but slightly different initial starting conditions in the atmosphere and oceans), † = projected climate at 2xCO_2 levels, ‡ = projected climate change during 2070-99 time slice, § = projected climate change over Canada's land area

the UKMO GCM scenario. The more recent IPCC *SRES* (IPCC 2001) further extended the upper bounds of greenhouse gas emissions and the range of projected global climate change (from 1.0 to 3.5°C in the *SAR* to 1.4 to 5.8°C in the IPCC 2001 TAR). Because the older equilibrium GCM scenario UKMO projects greater climate change, the model was retained in this analysis to illustrate the magnitude of vegetation change that may result from the upper range of temperatures projected by the more recently available *SRES*-based climate change projections (i.e., A1F1, A1B, or A2 scenarios in IPCC 2001).

The terrestrial vegetation change modelling analysis was completed in the following steps:

(1) GCM data were interpolated to a 0.5° latitude/longitude grid and compared to a 30-year baseline average (i.e., 1961 to 1990) (see Neilson 1998 for additional details).

(2) General Vegetation Models (GVMs) were imported into ArcView geographic information system (GIS) and vegetation classifications were georeferenced and assigned a designation number (e.g., tundra grid cells were assigned a designation of 2, boreal conifer forest grid cells were designated 3, etc.).

(3) GVM grids were interpolated to shape files (polygons) and the vegetation classification designations were preserved in ArcView GIS.

(4) Ontario provincial park geocentroids were extracted from the CCAD (CCAD 2003). Georeferenced park geocentroids (latitudinal and longitudinal location of a park) were overlaid on the GVM scenarios and spatially joined with the GVM polygons (biome designation) thereby assigning data from a polygon to a point (park and protected area).

(5) Provincial park location and vegetation type attributes (park geocentroid and biome designation) were spatially joined to determine park biome type and representation change under current and simulated MAPSS and BIOME3 models. By assigning data to a location, the spatial relationships between parks and current and GCM simulated biogeography models could be determined.

(6) Polygon and point data were assessed quantitatively to determine: (i) potential biome climate type change in each park relative to current conditions; and, (ii) potential biome climate representation change in each park for each GVM scenario.

The results of the equilibrium GVMs used in this analysis depict the potential for substantial biome climate type change in Ontario's provincial parks system. These results should be considered indicative of the direction

and potential magnitude of vegetation change only, and not a precise prediction about the future distribution and composition of biomes in Ontario. It is important to note that the analyses reviewed in Step 2 suggest that species' climate envelopes respond individually and not as cohesive units as projected by the GVMs used here.

Neither GVM used in this study includes current or past land-use practices. For example, a natural grassland ecosystem might actually be shrubland in response to grazing or fire suppression (Neilson 1998). However, the 'potential' natural land-covers simulated by the models do provide an accurate estimate of the land-surface potential because they project that only certain vegetation types can grow in areas that support their necessary hydrological and physiological requisites (e.g., a forest cannot grow in a desert) (Neilson 1998). Given the structural differences in GVMs and their different response sensitivities to climate change in previous inter-comparison studies (e.g., VEMAP Members 1995, Neilson 1998), two GVMs were used to represent the range of assumptions and scientific uncertainties related to vegetation response to climate change (i.e., vegetation change through time).

Equilibrium GVMs do not model the transient response of vegetation to climate change and do not incorporate many other important factors influencing the complexities of vegetation change (e.g., species migration rates, soil forming processes, altered competitive relationships, human interference with natural adaptation processes [including migration], and changes in disturbance regimes – insect, disease, fire, extreme climate events such as drought and wind) (Scott *et al.* 2002). Additional concerns about the use of equilibrium GVMs are outlined in Woodward and Beerling (1997). A number of research groups are developing dynamic global vegetation models (DGVMs) to address some of the limitations of equilibrium GVMs and produce more realistic predictions of the transient response of vegetation to climatic change.

Given the limitations of equilibrium GVMs, the composition and distribution of vegetation that results in provincial parks under the changed climatic conditions near the end of the 21st century may be different from the potential vegetation modelled in this analysis.

Step 4: Fire Severity Change Modelling Analysis

Step 4 involved an assessment of fire severity change in Ontario provincial parks using the CGCM2 for the 2050s (doubled-CO_2) and 2090s (tripled-CO_2). This section also examines the potential implications of climate change for the OMNR's *Fire Management Policy for Provincial Parks and Conservation Reserves* (OMNR 2004a).

Following the work of Stocks *et al.* (1998, 2000), we used fire weather data from the 1980s and the Canadian General Circulation Model (CGCM2) (Boer *et al.* 1992, McFarlane *et al.* 1992) to compare the intensity and spatial distribution of current and projected (2050s and 2090s) seasonal levels of fire weather severity across Canada. For each grid point in the CGCM2, average monthly temperature, relative humidity, wind speed, and precipitation anomalies (differences between the baseline, doubled-CO_2 and tripled-CO_2 CGCM2 runs) were determined. In this approach, fire severity values were used to assess the relative fire potential based solely on weather, independent of forest vegetation and fuel conditions (Stocks *et al.* 2000).

We define fire severity as the potential increase in forest fire activity (i.e., the increase in geographical extent and length of the forest fire season, consistent with Stocks *et al.* 1998 and 2000). Temperature and precipitation changes for doubled-CO_2 and tripled-CO_2 runs were combined with baseline weather data for the 1980 to 1989 period. Severity values of 1 to 7 were assigned to illustrate fire severity in Ontario provincial parks. Values of <1 equate to *low* fire potential, values between 2 and 3 represent *moderate* potential, values between 4 and 5 constitute *high* and *very high* potential, and values >6 represent *extreme* forest fire potential.

Stocks *et al.* (1998) found a strong similarity in the geographical pattern of fire severity for four GCM models (i.e., the Canadian Climate Centre GCM, Hadley Centre GCM, Max Planck Institute for Meteorology GCM, and the National Centre for Atmospheric Research GCMs) using a doubled-CO_2 climate, which suggests that the predicted

change can be interpreted with some confidence. In general, change includes an earlier start to the fire season and large increases in the aerial extent of fire severity under both the doubled-CO_2 (Stocks *et al.* 1998, 2000) and tripled-CO_2 (Stocks *et al.* 2000) climate scenarios, particularly in central Canada. Within Ontario, Stocks *et al.* (2000) project that fire will increase across the province, with *high, very high,* and *extreme* rankings becoming dominant throughout northwestern, southwestern, and central Ontario by the 2090s.

We used the same CGCM2 model as Stocks *et al.* (2000) to illustrate potential forest fire severity change in Ontario's system of provincial parks for doubled-CO_2 (2050s) and tripled-CO_2 (2090s). While informative, an analysis of this type does not reflect the rate of change in fire climate and fire regimes as GHG concentrations increase and result in the equivalent of doubled-CO_2 and tripled-CO_2 levels (Stocks *et al.* 1998).

Provincial park boundaries were overlaid on the baseline (1980 to1990), doubled-CO_2 (2050s), and tripled-CO_2 (2090s) scenarios using ArcGIS software. Layers were joined to determine the spatial relationships between provincial parks and fire severity ranking values.

Step 5: Implications for Protected Areas Planning, Policy and Management in Ontario

Using the data and information developed in Steps 1-4, we examined the policy and planning implications of climate change for Ontario's provincial park system – particularly Ontario Parks' system planning policies, individual park mandates, and park management plans.

Results

Step 1: Literature Review

Introduction

Protected areas are established to help maintain ecosystem health, protect biodiversity and provide recreational opportunities for people. Studies indicate that the impacts of climate change on biodiversity conservation in Canada will be significant (Scott *et al.* 2002, Scott and Lemieux 2005, Lemieux and Scott 2005, Welch 2005, Scott and Lemieux 2007). For example, many protected areas have been designed to protect specific natural features, species and communities *in-situ*, and do not account for shifts in ecosystem location resulting from climate change. In this context, a recent report by the World Wildlife Fund (2003: 1) emphasized that "*...protected areas offer a limited defense against problems posed by rapid environmental change [and] protected areas will themselves need to be changed and adapted if they are to meet the challenges posed by global warming.*" A number of authors contend that climate change has the potential to undermine more than a century of conservation efforts (e.g., Scott *et al.* 2002, Hannah *et al.* 2002).

The Ecological Implications of Climate Change

Climate is a major factor that affects the distribution, abundance, and relationships of plants, animals, and other organisms. As Woodward (1987) and others (e.g., Bailey 1996) demonstrate, plants reproduce and grow only within a specific range of temperatures and respond to given amounts and seasonal patterns of precipitation. Likewise, animals have definitive temperature and precipitation requirements and are dependent on continued access to suitable habitat, including prey species. Changes in climatic variables such as temperature and precipitation affect biodiversity directly through changes in phenology (e.g., earlier flowering by trees or egg-laying by birds), in distribution (e.g., pole-ward shifts in ranges), and in physiology (e.g., sex determination), and affect biodiversity indirectly by altering relationships between species (Parmesan and Yohe 2003, Crick 2004, Parmesan 2005, and others).

Past Climate and Ecological Change

Spatially explicit analyses of pollen and macro-fossil datasets indicate that past changes in climate resulted in major shifts in ecosystem composition, structure, and function, including major shifts in species ranges in an unfragmented global landscape (e.g., Delcourt and Delcourt 1987, Liu 1990, Tallis 1990, Williams 2002). Analyses also suggest that species responded individually and not as cohesive units (Liu 1990, Prentice and Webb 1998).

In Ontario, the early post-glacial boreal forest that colonized the Canadian Shield after 10,000 years before present (B.P.) was dominated by white spruce (*Picea glauca*) with little or no black spruce (*Picea mariana*) (Liu 1990). White spruce declined and was replaced by jack pine (*Pinus banksiana*) after 9,000 B.P. in response to a warmer climate. Subsequently, boreal forest was replaced with a complex mosaic of conifers and northern hardwoods (Delcourt and Delcourt 1987). Central Ontario boreal forest was transformed into Great Lakes-St. Lawrence forest around 7,400 B.P. and white pine continued to spread northward during a warm period that occurred 7,000 to 3,000 B.P. causing the boreal forest and the Great-Lakes St. Lawrence forest ecotone to advance approximately 140 km north of its current location (Delcourt and Delcourt 1987, Liu 1990) (Fig. 4). Lessa *et al.* (2003) found that over the same period the ranges of several boreal animal species, including black bear (*Ursus americanus*) and the northern flying squirrel (*Glaucomys sabrinus*), rapidly colonized new habitats. Pollen analyses of the mixed forests of southern Ontario indicate that during the Little Ice Age cooling, between 1300 and 1850 A.D., beech (*Fagus grandifolia*) was replaced first by oak (*Quercus spp.*) and then by pine (*Pinus spp.*) (Campbell and McAndrews 1993).

Projected Ecological Change

Due to a number of interacting factors, including reduced periods of snow cover and associated loss of albedo, reduced ice cover, and warmer oceanic temperatures, greater climatic change is expected at northern latitudes. Compared to other countries in mid to southern latitudes, most vegetation scenarios show potential for massive

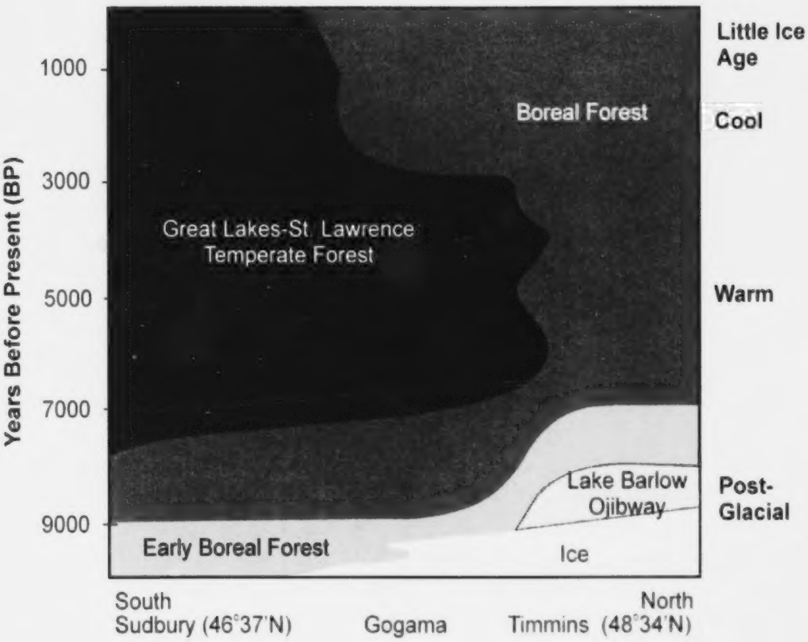


Figure 4. A spatial-temporal reconstruction of the regional vegetation history of northern Ontario (adapted from Liu 1990).

change of plant species distribution in Canada (Environment Canada 1998). Rizzo and Wiken (1992) modelled the spatial shifts of 10 Canadian ecoclimatic provinces (classified by the Ecoregions Working Group 1989), using the Goddard Institute for Space Studies (GISS) doubled-CO_2 equilibrium GCM. The projected large spatial shifts in ecoclimatic provinces, including a decline of arctic (from 26.1 to 20.2% of its surface area) and subarctic zones (from 20 to 7.8% of its surface area), a 50% decline of the boreal forest, a 500 km northward shift of the remaining boreal forest, the displacement of the subarctic in Québec and Labrador by boreal forest, the expansion of cool temperate forests over much of eastern Canada south of James Bay, a 6.9% expansion of grassland throughout the prairie region, and the emergence of semi-desert ecosystems in southern Saskatchewan and Alberta.

In a more recent study, Malcolm and Markham (2000) used seven GCM experiments with MAPSS and BIOME3 to produce 14 distribution scenarios of global vegetation under doubled-CO_2 conditions. The scenarios project that large areas of the Northern Hemisphere will experience "habitat change" (areas where current and future biome types change), high "required migration rates" (RMRs) (i.e., speed that species might be required to move to keep up with projected warming), and a reduction in species diversity (due to reductions in the area of habitat patches remaining after warming). However, the authors do not address the possibility of increases in species diversity and the formation of new ecosystems.

Changes of existing habitats from one biome type to another were markedly concentrated in the north, especially Canada with an average projected 'habitat change' of 55.8% (as a percentage of total land area) (Malcolm and Markham 2000). Six provinces and one territory were projected to experience habitat change in more than 50% of the area (Yukon Territory – 64.1%, Newfoundland and Labrador – 63.6%, British Columbia – 60.4%, Ontario – 61.4%, Québec – 59.5%, Alberta – 56.4%, and the Manitoba – 52.9%). New Brunswick (44.7%), Nova Scotia (34.2%), Northwest Territories and Nunavut (33%), Saskatchewan (24.8%), and Prince Edward Island (0%) were projected to change the least.

Malcolm and Markham (2000) calculated RMRs by dividing the migration distance (calculated as the distance between a future location and the nearest same biome type location in the current climate) by the time period over which the migration occurs. High RMRs, defined as migration rates of ≥1,000 m/yr, was projected for 33.1% of Canada's total land area (8th highest among the 20 countries included in the analysis), and the authors emphasized that migration barriers (e.g., roads and communities) negatively affected the ability of some organisms to migrate. High RMRs were projected for Ontario (49.2%), Newfoundland (48.3%) and Québec (47%). In many instances where low habitat change was projected (e.g., New Brunswick and Prince Edward Island), lower RMR values were also projected (10.9% and 11.9%, respectively). The highest RMRs were projected for the taiga/tundra, temperate evergreen forest, temperate mixed forest, and boreal coniferous forest biomes, indicating that species living in these systems may be among the most vulnerable to global change. 21st century RMRs in many Canadian ecosystems are projected to be 10 times greater than the actual migration rates of species after the last glacial retreat (Malcolm and Markham 2000).

Alarmingly, Malcolm and Markham (2000) concluded that climate change "*...has the potential to eventually destroy 35% of the world's existing terrestrial habitats, with no certainty that they will be replaced by equally diverse systems or that similar ecosystems will establish themselves elsewhere.*" Furthermore, Malcolm and Markham (2000) emphasized that although some plants and animals will be able to rapidly migrate, many others will not (although the authors do not identify which specific species will be able to adapt or not). The projected habitat change and high RMRs could increase the risk of species extinctions in Canada.

Recent species-level modelling for Ontario by Malcolm *et al.* (2004) (Figs. 5 and 6) show that southern species such as red maple (*Acer rubrum*) could increase in distribution and density in Ontario, while more common northerly species, such as black spruce could decrease in distribution and density in Ontario. Malcolm *et al.* (2004) found that as many as 30 tree species currently not found in Ontario could appear under the projected warmer climate of the late 21st century. For example, climate change scenarios depicting small and large change projected the northward migration of several species currently restricted to the U.S. into the Lake

Simcoe-Rideau region (Ecoregion 6E), including black hickory (*Carya texana*) and shortleaf pine (*Pinus echinata*) (Malcolm *et al.* 2004). These scenarios also project the migration of osage-orange (*Maclura pomifera*) and post oak (*Quercus stellata*) into Carolinian ecosystems in southwestern Ontario. Some climate change models projected post oak to establish itself as a widespread species in Ontario (range size >100,000 km^2) expanding its geographical extent beyond the Carolinian ecosystem into the Lake Simcoe-Rideau Region (Ecoregion 6E) and, under a few scenarios, the Ontario Shield Ecozone. Assuming that suitable conditions exist to allow for the successful migration of these southern species, this is one of the first studies to suggest that climate change may result in an increased number of species in Canada.

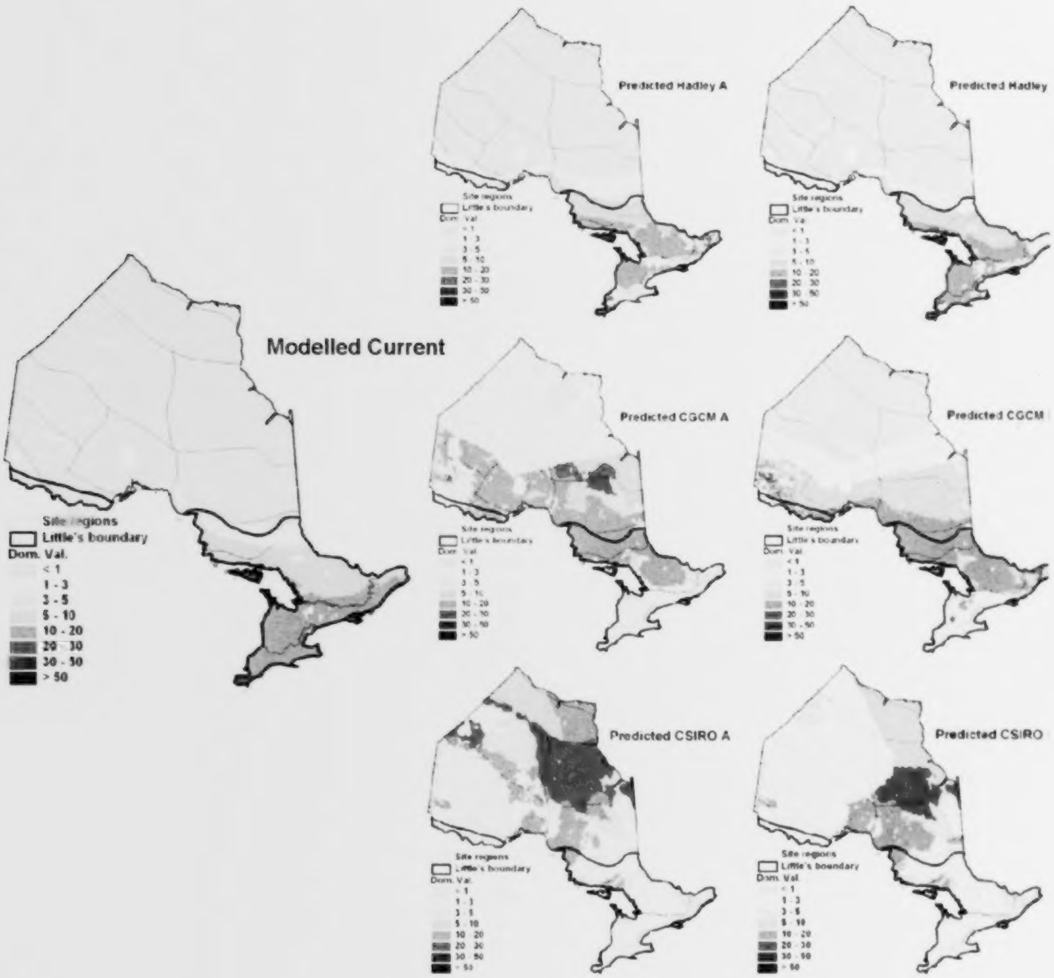


Figure 5. Modelled current and future distribution of red maple (*Acer rubrum*) in Ontario using six climate model scenarios (Malcolm *et al.* 2004).

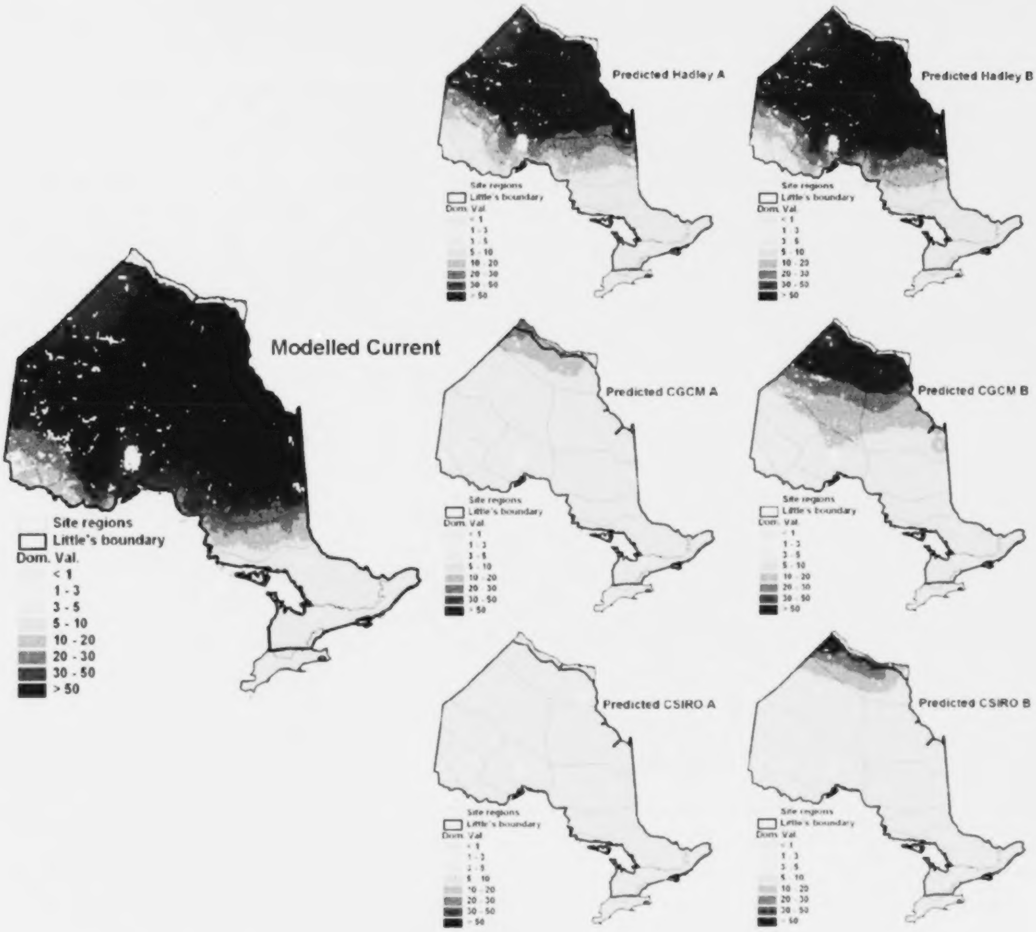


Figure 6. Modelled current and future distribution of black spruce (*Picea mariana*) in Ontario using six climate model scenarios (Malcolm *et al.* 2004).

Implications of Climate Change for Other Ontario Parks Assets

Ecological Values

Changing water conditions (e.g., water level and temperature) in the Great Lakes are likely to be one of the most important climate change-related impacts in Ontario (IJC 2003). Projections suggest that future Great Lakes water levels will decline to or below historical low levels as a result of accelerated evaporation (Mortsch *et al.* 2000; Lavender *et al.* 1998) (Table 4).

Water level decline will impact shoreline habitats and wetlands in provincial parks throughout the Great Lakes region. In some cases, this could lead to the formation of new ecosystems. For example, marshes and fens bordering shorelines could dry and be colonized by ceda. s and other terrestrial species (Scott and Suffling 2000). In addition, the switch from a wetland to a terrestrial ecosystem may result in the loss of biodiversity.

Table 4. Climate change impacts on mean annual water levels in the Great Lakes (cm) using three general circulation model (GCM) scenarios (Mortsch *et al.* 2000; Lofgren *et al.* 2002 as tabled in IJC 2003).

Lake/River	Water Level Change (cm)						
	Canadian CGCM1			UK (HadCM2)			Canadian CCC
	2030	2050	2090	2030	2050	2090	$2xCO_2$
Superior	-22	-31	-42	+4	-1	+11	-23
Michigan-Huron	-72	-101	-138	+14	+3	+35	-162
Erie	-60	-83	-113	+11	+4	+27	-136
Ontario	-35	-53	-99	+25	+4	+1	-130
St. Lawrence at Montreal	--	--	--	--	--	--	-130

The anticipated drop in water levels will reduce erosion on beaches and lower the zone of wave action on cliffs. Current water levels are approaching historic lows in Lake Huron and the decrease in water levels has resulted in the exposure of an increased supply of sand for dune system structure and function (Byrne *et al.* 2004). For example, the lowering of lake levels at Pinery Provincial Park is causing a landward build-up of dunes (Byrne *et al.* 2004). Taylor *et al.* (2006) suggest that a 1m drop in water level at Presqu'ile Provincial Park could result in beach expansion on the west side of the park, the migration of the existing marsh into Presqu'ile Bay, and the long-term exposure of a tombolo that connects the islands to the mainland.

Provincially rare Arctic-alpine plant species along the shoreline of a number of Lake Superior provincial parks (e.g., Lake Superior, Michipicoten Island, Neys, and Sleeping Giant) such as alpine chickweed (*Cerastium alpinum*), drummond's mountain avens (*Dryas drummondii*), common butterwort (*Pinguicula vulgaris*), and mountain fir-moss (*Huperzia appalachiana*), likely will be negatively impacted by climate change. Some of these plants are as much as 1,000 km south of their normal range. While their presence is due to a number of factors, including wave and ice action, lower lake levels and increased surface water temperatures will jeopardize the survival of these disjunct species.

In the Northern Hemisphere, lake ice-out now occurs earlier and ice-in occurs later. For example, average freeze-up occurs about 13 days later and the average break-up date four days earlier than 140 years ago on Lake Simcoe (Fig. 7). Several Ontario provincial parks, including Sibbald Point, McRae Point, and Mara are located along the Lake Simcoe shoreline.

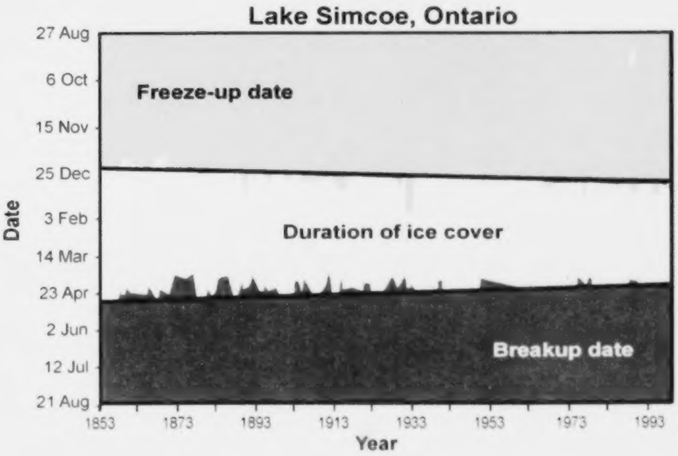


Figure 7. Freeze-up dates, break-up dates, and duration of ice cover for Lake Simcoe, 1853 to 1995 (CCME 2003).

Changes in the duration and extent of ice cover could increase risk to outdoor enthusiasts who depend on the ice for travel and/or pursue ice fishing as a recreational activity. Changes in ice formation rates and thickness can affect evaporation, lake levels, shoreline erosion, and lake-effect snow as well as ecosystem processes such as winter fish kills and overwinter survival of fish eggs (IJC 2003).

Lofgren *et al.* (2002) reported significant reductions in ice duration and extent on Lake Erie and Lake Superior under future climate change scenarios. For example, the CGCM1 scenario projects reductions in ice duration ranging from 12 to 47 days by 2030, 16 to 52 days by 2050, and 37 to 81 days by 2090. For Lake Superior, average annual surface water temperatures could increase between 5.1 to 7.4°C under a doubled-CO_2 climate (Table 5) and summer maximum surface water temperatures could reach temperatures greater than 20°C (Mortsch 1999). This could have important ecological and recreational implications for many provincial parks, including Lake Superior, Sleeping Giant, and Michipicoten Island.

Table 5. Great Lakes surface water temperature projections (°C) for three climate models (Mortsch 1999).

Lake	Climate Model Surface Water Projections (°C)		
	CCCMA-II	GFDL	GISS
Superior	+5.1	+7.4	+5.6
Michigan	+5.6	+5.5	+4.7
Huron	+5.0	+6.0	+4.7
Erie	+4.9	+5.0	+4.4
Ontario	+5.4	+5.9	+4.9

Changes in sea ice extent along the coastal areas of western James Bay and Hudson Bay could significantly affect polar bear (*Ursus maritimus*) access to feeding and denning habitat in Polar Bear Provincial Park (Obbard and Walton 2005). Surface and satellite-based observations show a decrease in sea ice extent over the past 46 years in the Northern Hemisphere and the GFDL and Hadley Centre GCM models project that this trend will continue with current GHG emission rates (Vinnikov *et al.* 1999) (Fig. 8). Recent ice monitoring results by the Canadian Ice Service indicate that, while variable, the annual spatial extent of Hudson Bay ice has decreased by about one third (IJC 2003). In addition, the ice-in period is shorter, and this decrease in ice cover period may be partially responsible for a decline in polar bear weight and the number of cubs they produce in the Hudson Bay region (Stirling *et al.* 1999, Obbard *et al.* 2006). Gough (1998) suggests that the seasonal ice cycle in Hudson Bay could disappear by 2040 under some of the more extreme climate change scenarios.

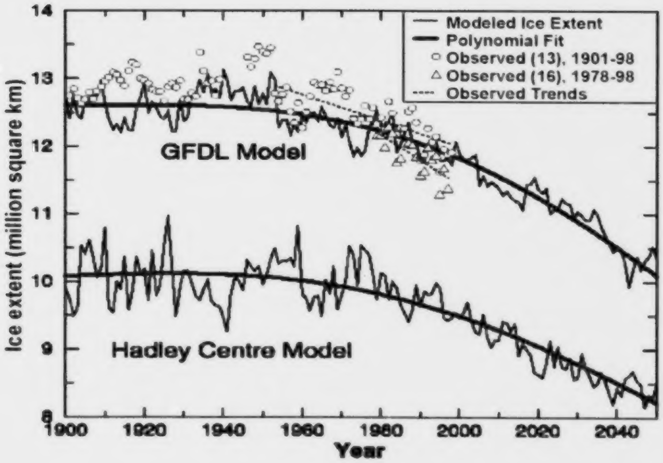


Figure 8. Modelled and projected northern hemispheric ice extent (Vinnikov *et al.* 1999).

Climate change will exacerbate the significance and complexity of the impacts of alien species in Ontario's ecosystems. *The Committee on the Status of Endangered Wildlife in Canada* (COSEWIC) defines an alien species as any non-Canadian native (indigenous) species, including exotic, non-native, non-indigenous, and invasive species (COSEWIC 2006). In the absence of an active management program, the impacts of alien species, a current stress in Ontario, could be exacerbated in a changing climate. For example, species now inhabiting more southerly ecosystems in the U.S. may move to new and emerging habitats in Ontario. Will natural resource managers need to redefine or clarify what is meant by invasive species? Should agencies accept that naturally occurring invasives will result from climate change and elect to focus control programs on Ponto-Caspian species (i.e., from the Caspian, Azov, and Black seas of eastern Europe) and other species that are accidentally or intentionally introduced by humans? The carp (*Cyprinus carpio*), zebra mussel (*Dreissena polymorpha*), purple loosestrife (*Lythrum salicaria*), curly-leaf pondweed (*Potamogeton crispus*), and Eurasion milfoil (*Myriophyllum spicatum*) exemplify the damage that can be caused by alien species. Climate change may exacerbate their impact, particularly if they are evolved to thrive in warmer climates.

Social and Economic Values

In Ontario, protected areas are a major resource for nature-based tourism, with more than 10 million person visits to operating parks alone in 2003. Jones and Scott (2006) assessed the potential impact of a changed climate on use of Ontario's protected areas and found that visitation was projected to increase 11 to 27% system-wide in the 2020s and 15 to 56% in the 2050s. When climate change was combined with the potential effects of demographic change, annual visits for the mid-2020s were projected to be even higher (23 to 41%) than that projected under climate change alone.

Visitation is projected to increase during July and August in all protected areas. Such an increase is highly relevant to a protected areas system that is more than 80% funded by user-fees and to protected areas with existing or potential visitor-related ecological stresses. Any increase in visitors during the peak tourism period strains protected area resources already operating near capacity during July and August. Perhaps more important to protected area managers in Ontario is that substantial increases in visitation are projected to occur before and after the traditional summer peak season period. This pattern is due to climate conditions becoming more suitable for warm-weather tourism during the spring (April to June) and fall (September to November) shoulder seasons. If sustained higher visitation occurs in the spring and fall months, Ontario Parks may find it necessary to extend the operating period of facilities in many parks.

In areas where climate change results in increased snowfall, opportunities for activities such as cross-country skiing may improve. On the other hand, climate change is projected to shorten the winter recreation season and decrease the reliability of suitable snow cover in many parts of Ontario. Marginally reliable or unreliable conditions for cross-country skiing and snowshoeing during winter holiday periods will negatively impact the economy of a number of communities in Ontario. For example, due to the uncertainty of snow conditions OMNR staff at Presqu'ile Provincial Park no longer groom cross-country ski trails.

Climate-induced water-level changes in Ontario's lakes and rivers will significantly affect recreation as well. For example, lower water levels potentially will restrict access to boating facilities, trails, and natural features of interest to visitors along the shoreline. Changes in water levels will also affect the ecological integrity and recreational potential of shoreline park systems where wetlands constitute important waterfowl habitat and a source of recreation for many people (Wall *et al.* 1985).

Globally, McCarty (2001) reported earlier breeding and migration dates in birds. Hughes (2000) has found that the warmer climatic events of the past century have advanced the timing of life-history cycles for insects, plants, birds, and amphibians. With increased temperatures, it is likely that the spring migration will occur earlier in the season and the fall migration will occur later. A study of migratory birds in Michigan (Carter 1999) found that 26 of 27 species arrive earlier in the spring than 30 years ago. At Presqu'ile Provincial Park, boardwalks

constructed through the marsh allow visitors to view the scenery and wildlife, and raised platforms have been constructed to maximize bird watching opportunities during migration and other periods. If the birds change migration routes in response to climate change, tourism may decline (Wall *et al.* 1985).

The fall colours attract many people to Ontario provincial parks in September and October. As the number of warmer days increases, the length of the autumn display period may increase as well. As exemplified in Figs. 4 and 5, some tree species are projected to expand or contract in range and density over the 21st century and beyond. This could affect the timing and intensity of fall colours. However, in the long-term the expansion of commonly found southern Ontario tree species into the north could provide visitors to more northerly provincial parks with new opportunities for fall foliage viewing.

Changes in fish species distribution and abundance in lakes and streams may also change sport fishing in Ontario provincial parks. As lake and river waters warm, cool and cold water fish habitat will disappear (Casselman 2002, Casselman *et al.* 2002) and habitat for warm water fish species will increase. This will influence not only where and when people choose to fish, but possibly the types of fish available to anglers.

The increased risk of forest fires resulting from climate change may require modified plans to protect park visitors when conditions are hazardous (Scott and Suffling 2000). In addition, an increase in the frequency of fire bans may detract from the park experience. An increase in the number of hot summer days may also reduce some recreation opportunities. Warmer water temperatures may increase potential for summer algal blooms and bacterial pollution (IJC 2003), resulting in potential beach closures. For beach-oriented provincial parks such as Wasaga Beach, Presqu'ile, Sandbanks and Pinery, this may lead to revenue losses. Finally, while increased economic benefits may result from an extended tourist season, the increase in number of users as well as longer period of use may increase the risk of ecological deterioration, which may need to be addressed in management plans and other activities.

Climate Change, Biodiversity and Protected Areas

Each species will respond to climate change in a unique way. Some species will micro-evolve (adapt *in-situ*) and/or survive within their individual phenological or physical limits, whereas others will be forced to migrate to more suitable climate and/or habitat (assuming there is suitable habitat to do so). In other cases, species will fail to adapt and disappear. Peters and Darling (1985) and Peters and Lovejoy (1992) suggest that when a species can no longer tolerate the climate envelope, extinction will occur. And in some cases, climate change will alter species interactions (e.g., predation or competition) and eliminate the species' niches. In other cases, organisms will migrate out of the parks and protected areas originally established to protect them.

Accordingly, Graham (1988) stressed the significance of including contingencies for climatic change in designing biological reserves. Graham (1988) concluded that although the mechanisms for survival are not yet known, species' ability to migrate to suitable new habitats and biological reserves designed for climatic fluctuations will be key survival factors.

Peters (1992) argues that intelligent plans for locating and managing reserves, require more knowledge about how changes in temperature, precipitation, CO_2 concentrations, and inter-specific interactions determine range limits and, most importantly, how these changes will cause local extinctions. Based on this conclusion, Peters (1992) recommended the establishment of multiple reserves for a given species to increase the probability of survival.

Malcolm and Markham (1997) reviewed the potential threats of global warming to a sample of U.S. national parks, and made several inferences about Canadian parks. Based on existing scientific literature, interviews and case studies, the authors concluded that the major threats to North American parks will be: (i) sea level rise and coastal inundation; (ii) vegetation change and species extinction, (iii) increased fire frequency and risk; (iv) vulnerability to invasive species, exotic weeds, and insect pests; and, (v) changes in precipitation patterns.

In addition to potentially losing mature indigenous forests in Canada's national parks, wildlife will also need to adapt as their habitat shifts (Scott and Suffling 2000). For example, Burns *et al.* (2003) project the loss of mammalian species in several U.S. national parks. With species losses projected as high as 20% in some parks, and drastic influxes of new mammalian species in southern parks, it is unlikely that many U.S. national parks will be able to meet their mandate of protecting current biodiversity within park boundaries. The study also noted that "*...as species assemblages change, new interactions between species may lead to less predictable indirect effects of climate change, increasing the toll beyond that found in this study*" (Burns *et al.* 2003: 11474).

Rowe (1989) and Lopoukhine (1990, 1991) identified climate change as a potential ecological stressor in Canada's national parks system, and the Ontario Wildlife Working Group (1991: 56), OMNR (1992a), and Gray *et al.* (1993: 104) identified climate change as a threat to Ontario's ecosystems and flora and fauna more than 15 years ago. In the 1997 *State of the National Parks Report* (Parks Canada 1997), climate change was identified as a stressor causing significant ecological impacts in seven (Fundy, Grasslands, Gwaii Haanas, La Mauricie, Mingan Archipelego, Pacific Rim and St. Lawrence Islands) national parks. In response to the issues identified in the 1990s, Parks Canada sponsored studies by Scott and Suffling (2000) and Scott *et al.* (2002) to examine the theoretical and empirical implications of climate change in Canada's national parks system. Scott and Suffling (2000) provided a screening level assessment of climate change impacts in Canada's national park system using existing literature and seasonal climate change scenarios (four doubled-CO_2 GCM experiments) for each national park. The 38 national parks were subdivided into six geographic regions (Atlantic, Great Lakes – St. Lawrence, Prairie, Western Cordillera, Pacific, and Arctic) where the range of anticipated climate change impacts will be similar. At a system level, Scott and Suffling (2002: xix) concluded that "*Climate change simultaneously represents a threat and opportunity to different species and ecological communities within the national parks system... The dynamic biogeography brought about by global climate change will effectively alter the 'rules' of ecological conservation... [and]... the strategic role of Parks Canada in an era of climate change requires much analysis and deliberation.*" Scott and Suffling (2000) recommend that climate change be integrated into Parks Canada's strategic planning and policy formulation.

Using six GCM forced GVM scenarios from the IPCC Regional Assessment (Neilson 1998), Scott *et al.* (2002) examined the extent to which vegetation distribution (biomes) might change in Canada's national park system. Tables 6 and 7 summarize the results from Scott *et al.*'s (2002) biome climate envelope change assessment for Canada's national parks.

In five of six scenarios, a novel biome climate envelope appeared in more than half of the national parks and greater than 50% of all vegetation within park boundaries changed by at least one biome type. The climate envelope for tundra and taiga/tundra biomes in the national park system declined in each of the future vegetation scenarios, while the climate currently influencing southerly biomes such as temperate forests and savanna/woodland increased (in some scenarios 2x to 4x). Results for climate in areas where boreal forest now occurs varied among the climate change scenarios depending on whether the boreal and taiga/tundra biomes have been separated (BIOME 3) or combined (MAPSS).

Based on the results presented above, it is possible that several Arctic disjunct species (e.g., those found in Lake Superior Provincial Park) could disappear with changes to the thermal habitat they have evolved to rely on. Conversely, some rare plants [e.g., pitch pine (*Pinus rigida*) and deerberry (*Vaccinium stamineum*) in Charleston Lake and Frontenac provincial parks] and reptiles [e.g., black rat snake (*Elaphe obsoleta*) in Charleston Lake Provincial Park] could migrate to more suitable habitat provided that the necessary migration conditions are in place. By the end of the century, Ontario's forests may be in the midst of considerable change resulting from climate warming. And although the modeling studies reviewed here differ in their methodologies, the direction of changes are generally similar.

Table 6. Proportional biome representation in Canada's national parks projected for current and future climate conditions (based on km^2) (Scott *et al.* 2002).

Biome Type	MAPSS					BIOME3		
	Current	GFDL*	GISS*	UKMO*	HadCM2*	Current	HadCM2*	MPI*
Tundra	35%	28%	26%	20%	30%	37%	22%	23%
Boreal + Taiga/ Tundra	46%	48%	43%	45%	43%	47%	39%	49%
Taiga/Tundra	19%	14%	17%	18%	13%	--	--	--
Boreal	27%	34%	26%	27%	30%	--	--	--
Temperate Evergreen Forest	8%	7%	14%	15%	19%	4%	1%	2%
Temperate Mixed Forest	8%	12%	14%	14%	16%	7%	26%	18%
Savanna / Woodland	2%	5%	2%	5%	2%	4%	11%	5%
Shrub / Woodland	0%	0%	0%	0%	0%	1%	1%	2%
Grassland	1%	1%	1%	1%	0%	0%	0%	0%
Arid Lands	0%	0%	0%	0%	0%	0%	0%	0%

* GCM acronym explanations are provided at the beginning of this report.

Table 7. Biome change in Canada's national parks projected for future climate conditions (change projected in number of parks) (Scott *et al.* 2002).

Type of change	MAPSS				BIOME3	
	GFDL*	GISS*	UKMO*	HadCM2*	HadCM2*	MPI*
Novel biome appears	21	20	22	20	18	14
Biome change in >50% of mapped grid cells	21	19	21	18	17	15

* GCM acronym explanations are provided at the beginning of this report.

Past changes in climate resulted in major shifts in species ranges and marked reorganization of biological communities. Most biota are adapted to changes in climate that occurred within the Pleistocene ranges (two million to 100,000 yrs B.P.) of atmospheric concentrations of CO_2, temperature, and precipitation. A recent report by the Secretariat of the Convention on Biological Diversity (SCBD 2003: 2) emphasized "*...warming beyond the ceiling of temperatures reached during the Pleistocene will stress ecosystems and their biodiversity far beyond the levels imposed by the global climate change that occurred in the recent evolutionary past.*" However, human-induced habitat fragmentation has confined some species to relatively small areas within their previous ranges, with reduced genetic variability. Many feel that fragmentation will reduce the ability of some species to adapt to new climate regimes.

Changes in ecosystem composition, structure, and function likely will require a re-assessment of approaches to biodiversity conservation in Canada and the rest of the world. It raises important questions about protected area systems with a mandate to include a representative sample of ecosystems and unique or rare species of provincial significance. This topic is discussed in more detail in Step 5.

Step 2: Historical Climate Analysis and Climate Change Projections for Ontario Provincial Parks

Twentieth and Early Twenty-First Century Climatic Trends

Global and Northern Hemisphere Climate Trends

Earth's climate will always change in response to its orbital behaviour, volcanic emissions, and other natural processes, human activity, and the sun. Glacial and interglacial periods result from the Earth's orbit and location relative to the sun. The most recent glacial period existed from about 25,000 to 18,000 B.P. Between 18,000 and 10,000 years B.P. temperatures increased and reached levels comparable to pre-industrial temperatures. Although humans began to add GHGs to the atmosphere with the invention of agriculture, the industrial revolution marked the beginning of the period during which human activities have contributed significantly to global warming. The cumulative build-up of GHGs, particularly since the 1940s, and the associated increase in temperature (Fig. 9) has begun to significantly affect ecospheric composition, structure, and function.

The United Nations (UN) Intergovernmental Panel on Climate Change (IPCC) is responsible for assessing the scientific evidence about climate change, summarizing and communicating it to people around the globe, and providing information that will assist governments with their efforts to manage for climate change. In 2001, the IPCC concluded that temperatures increased 0.6°C ±0.2°C during the 20th century (IPCC 2001). However, more recent analyses indicate that temperature increased by 0.6°C during the past three decades alone and by 0.8°C during the 20th century, suggesting that global twentieth and early twenty-first century warming was unprecedented in the past 10,000 years and is within approximately 1°C of the maximum temperature of the past one million years (Hansen *et al.* 2006). Moreover, the IPCC (2001) identified the 1990s as the warmest decade on record for the Northern Hemisphere; 1998 was the warmest year since 1861 and the twentieth-century was the warmest century in the past 1,000 years (Fig. 10).

Other important climatic changes have occurred as well. For example, winter snow cover in the Northern Hemisphere has decreased about 60% since the late 1960s (IPCC 2001). Similarly, there has been a reduction of about two weeks in the annual duration of lake and river ice cover in the mid- and high-latitudes of the Northern Hemisphere. Further, the global average sea level has increased 10 to 20 cms over the past century and ocean temperature has increased since the late 1950s (IPCC 2001). Finally, the IPCC (2001) reported that, while not spatially uniform over the mid- to high-latitudes of the Northern Hemisphere, precipitation has increased 0.5 to 1% per decade over the past century and that heavy precipitation events have increased 2 to 4% over the same period.

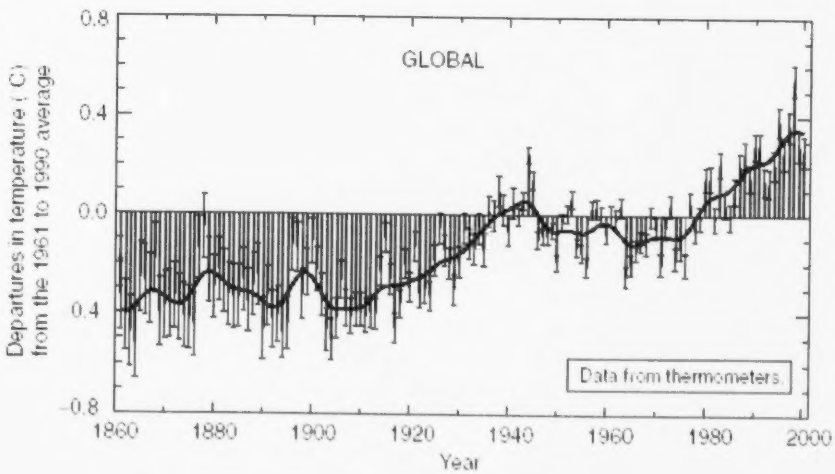


Figure 9. Measured variations in the Earth's temperature for the past 140 years (°C) (IPCC 2001).

Human influences will continue to alter Earth's atmospheric composition throughout the 21st century. The Working Group I contribution to the IPCC *Fourth Assessment Report* (FAR) estimates that temperatures could increase by 1.1 to 6.4°C by the end of the 21st century (IPCC 2007). The "best estimate" for the lowest emissions scenario has increased by 0.4°C since the release of the IPCC *Third Assessment Report* (TAR). As the IPCC (2007) emphasized, anthropogenic warming will continue for centuries due to the timescales associated with climate processes and feedbacks, even if greenhouse gas concentrations are stabilized.

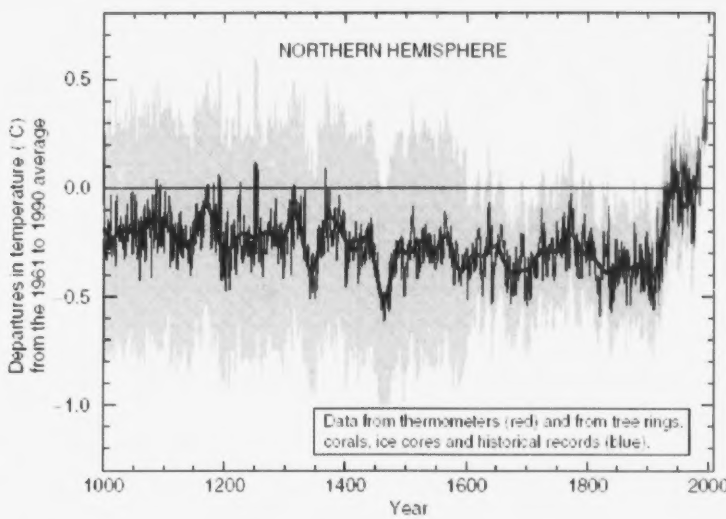


Figure 10. Variations in the Earth's temperature for the past 1,000 years (°C) based on data from ice cores, coral, tree rings, and measurements (IPCC 2001).

Canada and Ontario Climate Trends

Annual temperatures increased across Canada during the latter half of the 20th and early 21st centuries, with temperatures remaining above normal for the last ten years (Fig. 11). Over the past 59 years, Canada's annual temperature has increased 1.3°C; 1998 was the warmest year (+2.5°C) and 1972 the coolest (-1.8°C). The 2006 national average temperature was 2.4°C above normal (Environment Canada 2007). This places the year 2006 as the second warmest since nationwide records began in 1948. This temperature trend was consistent throughout most of Canada, except in the Pacific Coast and in the Northern British Columbia Mountains/Yukon Territory (Fig. 12).

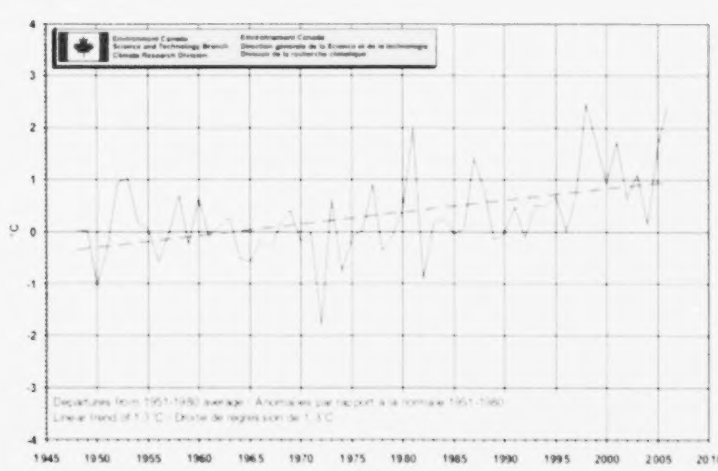


Figure 11. Mean annual temperature departures and long-term trend (°C) for Canada since 1948 (Environment Canada 2007).

In Ontario, the Great Lakes-St. Lawrence Lowlands temperatures have been consistently warmer than normal; 2006 ranked second among the warmest years on record (1.8˚C above average) and 1998 was the warmest year on record (2.3˚C above average). 2006 ranked first amongst the warmest years on record in the Northeastern Forest, with an annual average temperature 2.3˚C above average (Environment Canada 2007).

It was wetter than normal across Canada during 2003 to 2006, and since 1973 only three years have been drier than normal (Fig. 13). The second wetters year was 1996 (9.1% above average) and the driest was 1956 (7.3% below average). Canada experienced its wettest year on record in 2005 at 13.4% above average (Environment Canada 2007).

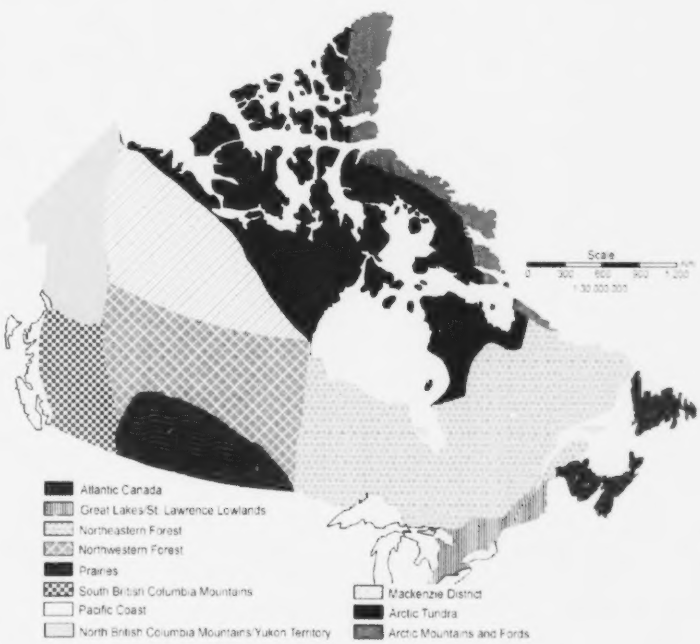


Figure 12. Canadian climate regions (Environment Canada 2006b).

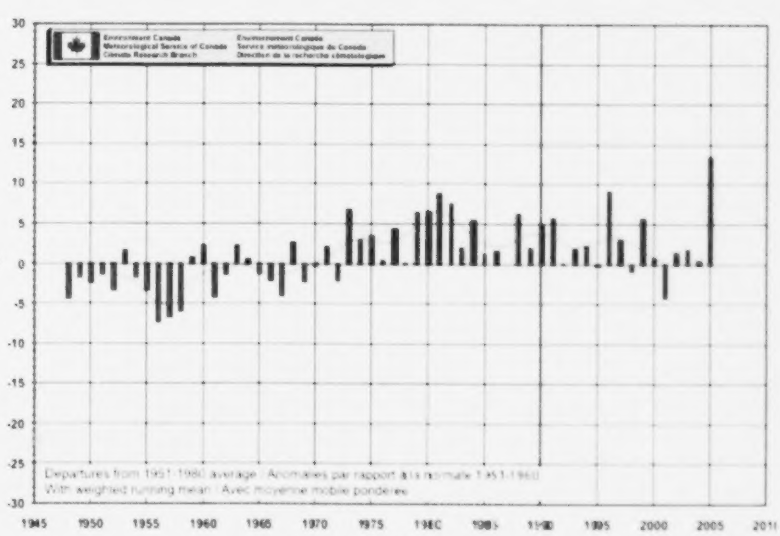


Figure 13. Mean annual precipitation departures and long-term trend (˚C) for Canada since 1948 (Environment Canada 2007).

Historical Climatic Variability and Trends in Ontario Provincial Parks

Results of the historical climate variability and trend analysis are displayed as mean annual temperature (MAT) (°C) and total annual precipitation (TAP) (mm) relative to the average of the 1961 to 1990 period. These results are presented in a manner consistent with other recent climate trend analyses, including those completed by Hamilton *et al.* (2001), the Province of British Columbia (2002), and the Canadian Council of Ministers of the Environment (CCME 2003). While most of the trends are based on long-term records (i.e., 80 to 100 years or more) and statistically reflect climate change, some are based on shorter records (e.g., approximately 60 years) and likely reflect natural climate variability more than climate change.

According to the Province of British Columbia (2002), the ideal would be to report only on trends that can be attributed to climate change – trends that are both statistically significant and based on long-term historical records. However, because climate data for many stations in Ontario only date back to the mid-20th century and are sometimes fragmented, we describe trends and variability based on available records, regardless of whether it is considered long enough to link the trends definitively to climate change. Moreover, in a few cases, data were not available for the entire 1961 to 1990 period to calculate accurate averages for temperature and precipitation. For these and other reasons discussed in the Methods section, some of the trends documented in this report should be interpreted with caution and may need to be adjusted in the future. Nevertheless, they are based on the best available data and are the only instructive means with which information on climate variability and trends in Ontario can be calculated and interpreted.

A historical climate regime was analyzed for a geographically representative sample of provincial parks to illustrate historical variability and trends in MAT and TAP during the 20th and early 21st centuries (Table 8, Figs. 14 and 15). While statistical significance varied, MAT increased at all stations used in the analysis over their respective historical records compared to 1961 to 1990. Results showed with $\alpha = \leq 0.01$ statistical significance that the greatest increase in MAT over the historical record occurred in Tidewater (Moosonee Station, +1.24°C) and Wabakimi (Sioux Lookout Station, +1.19°C) provincial parks. Conversely, Rondeau Provincial Park experienced the least temperature change over the historical record (Ridgetown ACS Station, +0.32°C) and a statistical significance test identified no trend. Of note, seven of the 11 stations used in this analysis illustrated MAT increases greater than 0.90°C with a statistical significance of $\alpha = \leq 0.05$. Five stations recorded MAT increases greater than 1.0°C.

Four of the 11 climate stations analyzed for MAT variability and trends recorded the warmest five year mean temperatures on record in the past five years of their respective record (in most cases 2000 to 2004) (Table 9). Five stations experienced their warmest five-year mean temperatures on record between 1995 and 1999. Therefore, for nine of the 11 stations used in this study, the last decade on record was the warmest. Ridgetown Station (Rondeau Provincial Park) and Mine Centre Station (one of three stations used for Quetico Provincial Park) were the only stations not recording the warmest grouped five year mean temperature in the last ten years (1951 to 1955 for Ridgetown and 1980 to 1984 for Mine Centre).

Total annual precipitation (TAP) increased in all but Lake Superior Provincial Park over the historical record when compared to 1961 to 1990. TAP increased >100 mm at three of six stations and two stations recorded increases in annual precipitation >200 mm. Precipitation increases at two of seven stations were statistically significant at $\alpha = \leq 0.01$ (North Bay A for Algonquin Park and Thunder Bay A for Quetico Provincial Park) (Table 8).

Table 8. Summary of mean annual temperature (MAT) and total annual precipitation (TAP) departure trends for provincial parks used in this analysis. More information about how the Environment Canada (2006a) climate data were constructed can be found in Vincent (1998), Vincent and Gullet (1999), and Vincent *et al.* (2002).

Provincial Park/Station	MAT Trend Over Record (°C)	TAP Trend Over Record (mm)
Rondeau Provincial Park (Southwest Zone)		
Ridgetown ACS (adj)	+0 .32 [4]	+ 106.4 [3]
Algonquin Provincial Park (Algonquin Zone)		
North Bay A (adj)*	+0 .84 [3]	+ 219.3 [1]
Haliburton (adj)	+0 .63 [3]	na
Sandbanks Provincial Park (Southeast Zone)		
Belleville (adj)	+ 1.14 [1]	na
Lady Evelyn-Smoothwater Provincial Park (Northeast Zone)		
Earlton A (adj)	+1.14 [1]	+24.71 [4]
Quetico Provincial Park (Northwest Zone)		
Thunder Bay A (adj)	+ 1.06 [1]	+231.07 [1]
Mine Centre (adj)	+ 0.90 [2]	na
Fort Frances A (adj)	+ 0.98 [1]	na
Wabakimi Provincial Park (Northwest Zone)		
Sioux Lookout A (adj)	+ 1.19 [1]	+32.42 [4]
Lake Superior Provincial Park (Northeast Zone)		
Wawa A (adj)	+ 0.88 [3]	-80.0 [4]
Tidewater Provincial Park (Northeast Zone)		
Moosonee (adj)	+ 1.24 [1]	na

(1)= trend significance at 99% level or greater, (2)= trend significance between 95-98% level, (3)= significance level between 90-94% level (weak significance), (4)= no trend (fails to reveal a trend that is statistically significant at the 90% level or greater), na = data set not applicable to variable, adj = homogenized adjusted data

Figure 14. Summary map of mean annual temperature (MAT) trends over the historical records for provincial parks used in this study.

1= trend significance at 99% level or greater.
2= trend significance between 95-98% level.
3= significance level between 90-94% level (weak significance).
4= no trend (fails to reveal a trend that is statistically significant at the 90% level or greater).

Figure 15. Summary map of total annual precipitation (TAP) trends over the historical records for provincial parks used in this study.

1= trend significance at 99% level or greater.
2= trend significance between 95-98% level.
3= significance level between 90-94% level (weak significance).
4= no trend (fails to reveal a trend that is statistically significant at the 90% level or greater).

na= data set not applicable to variable.

Table 9. Warmest five year period, warmest five individual years, coolest five-year period, and coolest five individual years for stations representing provincial parks.

Station	Warmest five-year period	Five warmest years	Coolest five-year period	Five coolest years
Rondeau Provincial Park (Southwest Zone)				
Ridgetown ACS (adj)	1951-1955	1998, 1949, 1987, 1931, 1953	1976-1980	1924, 1926, 1978, 1940, 1976
Algonquin Provincial Park (Algonquin Zone)				
North Bay A (adj)	1995-1999	1998, 1999, 2001, 1953, 1987	1940-1944	1940, 1972, 1943, 1976, 1980
Haliburton (adj)	2000-2004	1998, 1999, 1931, 2001, 1932	1940-1944	1904, 1917, 1940, 1943, 1934
Sandbanks Provincial Park (Southeast Zone)				
Belleville (adj)	1995-1999	1998, 1999, 2001, 2002, 1953	1940-1944	1923, 1926, 1940, 1924, 1934
Lady Evelyn-Smoothwater (Northeast Zone)				
Earlton A (adj)	1999-2003	1998, 2001, 1999, 1987, 1953	1939-1943	1950, 1972, 1939, 1943, 1978
Quetico Provincial Park (Northwest Zone)				
Thunder Bay A (adj)	1997-2001	1931, 1998, 1987, 1999, 2001	1916-1920	1917, 1912, 1950, 1907, 1936
Mine Centre (adj)	1980-1984	1998, 1931, 1981, 1987, 1941	1915-1919	1917, 1950, 1924, 1972, 1996
Fort Frances A (adj)	2000-2004	1931, 1987, 1998, 1999, 1941	1915-1919	1917, 1916, 1950, 1924, 1996
Wabakimi Provincial Park (Northwest Zone)				
Sioux Lookout A (adj)	1995-1999	1998, 1987, 1931, 2001, 1999	1965-1969	1950, 1972, 1936, 1951, 1966
Lake Superior Provincial Park (Northeast Zone)				
Wawa A (adj)	2000-2004	1998, 1987, 2001, 1999, 1991	1965-1969	1950, 1972, 1956, 1976, 1989
Tidewater Provincial Park (Northeast Zone)				
Moosonee (adj)	1995-1999*	1998, 2001, 1999, 1987, 1952	1925-1929	1917, 1933, 1936, 1912, 1972

* = 1995-1999 and 2000-2004 are the only two five-year grouped records with an average temperature above 1.0°C at this particular park.

Future Climate of Canada and Ontario

Canada is projected to warm more than most other countries. For example, 32 SRES GCM experiments projected annual mean temperature increases of 3.1 to 10.6°C by the 2080s over Canada's terrestrial area, about double the projected global average increase (PCIC 2006). In Ontario, *SRES* GCM simulations suggest an increase in annual mean temperature between 0.7 and 3.1ºC for the 2020s, 1.9 and 6.9ºC for the 2050s, and 2.7 and 10.6ºC for the 2080s (PCIC 2006) (Fig. 16). Generally, total annual precipitation is also projected to increase in Ontario. The same 32 GCM experiments projected mean annual precipitation changes of -0.2- to +8.7% for the 2020s, +0.3to 16.7% for the 2050s, and +2.5 to 19.2% for the 2080s (Fig. 17). Such changes in temperature and precipitation over a relatively short period could have significant consequences for society and for Ontario's ecosystems, their constituent organisms, and for agency staff who are responsible for managing them.

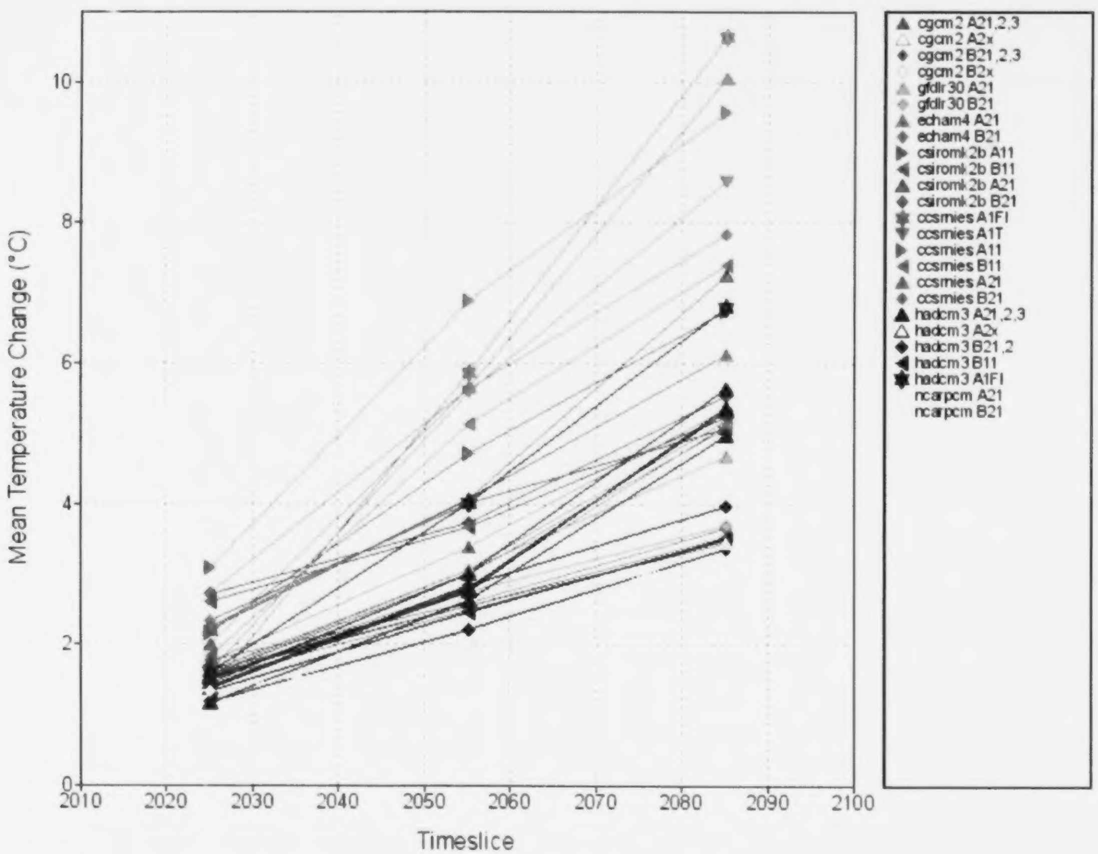


Figure 16: Projected mean annual temperature change in Ontario using a variety of general circulation models (GCM) and emission scenarios (SRES) for the 2020s, 2050s, and 2080s (PCIC 2006). See Appendix 3 for an explanation of GCM acronyms.

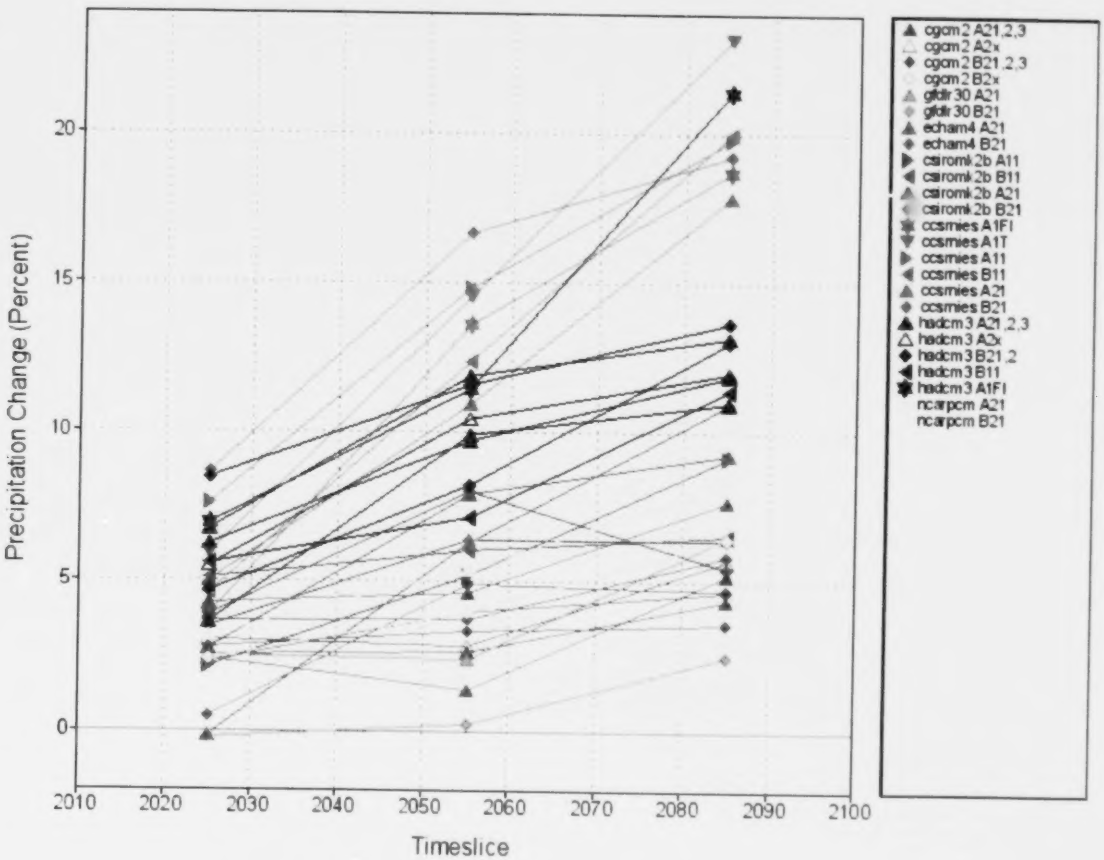


Figure 17. Projected percentage change in mean annual precipitation in Ontario using a variety of general circulation models (GCMs) and emission scenarios (SRES) for the 2020s, 2050s, and 2080s. See Appendix 3 for an explanation of GCM acronyms.

Climate Change Projections for Ontario Provincial Parks

Figs. 18 and 19 highlight the range of GCM results projected for provincial parks in this study. Temperature and precipitation scatterplot summaries for each park are presented in Appendix 3. Most parks are projected to experience annual temperature increases of 1.8 to 3.2°C in the 2020s, 1.8 to 7.0°C in the 2050s, and 2.5 to 10.0°C in the 2080s. Greatest changes in temperature are projected for northern parks, including Tidewater Provincial Park (2020s: +0.9 to 2.9°C, 2050s: +2.1 to 7.4°C, 2080s: +2.1 to 12.7°C) and Wabakimi Provincial Park (2020s: +0.7 to 3.4°C, 2050s: +2.1 to 7.8°C, 2080s: +2.7 to 12.5°C). Minimum and maximum projected changes in temperature and precipitation varied considerably among the parks analyzed, years (e.g., 2020s, 2050s, and 2080s), and scenarios (Appendix 3).

Precipitation was projected to change most for Tidewater Provincial Park in the Northeast Zone and least for Rondeau Provincial Park in the Southwest Zone (Appendix 3). Projected large increases in evaporation over land due to rising air temperatures will more than offset minor increases in precipitation. Changes in the regional and temporal patterns and intensity of precipitation are also expected, increasing the tendency for extreme droughts and floods (Stocks *et al.* 1998).

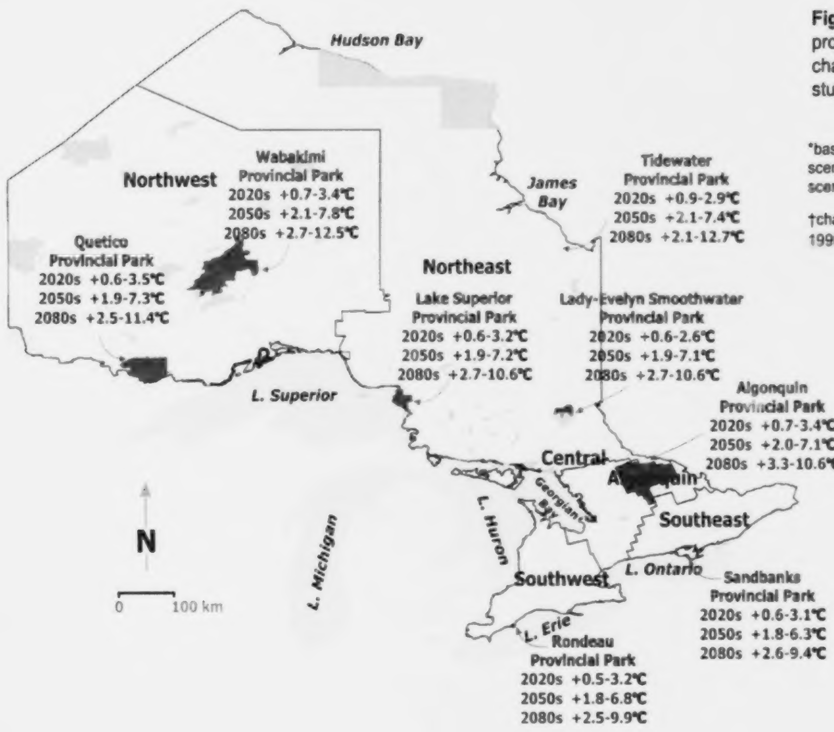


Figure 18. Map illustrating projections of temperature range changes (°C) for parks used in this study*†.

*based on the output of 25 SRES scenarios (see Appendix 3 for detailed scenario projections).

†changes are with respect to the 1961-1990 mean period.

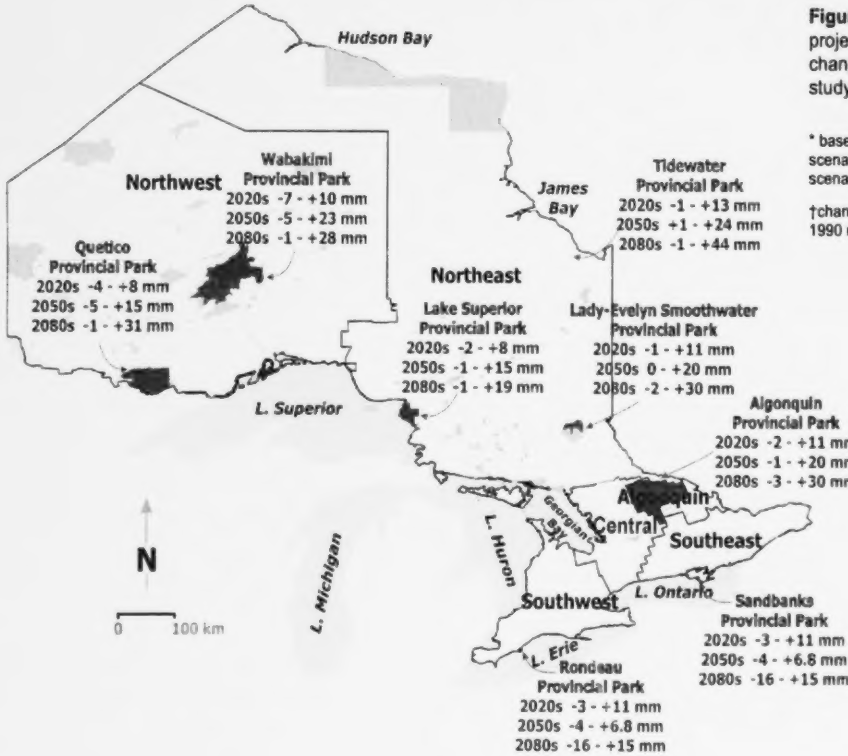


Figure 19. Map illustrating projections of precipitation range changes (%) for parks used in this study*†.

* based on the output of 25 SRES scenarios (see Appendix 3 for detailed scenario projections).

†changes are with respect to the 1961-1990 mean period.

Historical and Projected Climates for Individual Provincial Parks

Rondeau Provincial Park (Southwest Zone)

Rondeau Provincial Park was coolest in the early part of the 20th century and from about 1960 to the mid 1970s. The warmest periods on record occurred from 1950 to about 1960 and the late 1990s. Rondeau recorded the least change in MAT of all the provincial parks in this study (+0.32°C) with no significant trend. TAP increased 106.4 mm over the historical record, however, the trend was weakly significant ($\alpha = \leq 0.06$). SRES scenarios project Rondeau's average annual temperature to increase by 0.5 to 3.2°C in the 2020s and 2.5 to 9.9°C in the 2080s. While precipitation projections were quite variable, most scenarios project increased precipitation for all years examined. Projected precipitation increases were as high as 15% for the 2080s. Conversely, some scenarios project sharp declines (up to 16%) in precipitation.

Algonquin Provincial Park (Algonquin Zone)

Weather stations representing Algonquin Provincial Park recorded a warm period between the mid 1970s and early 1990s and from 1998 to 2004. Cooler temperatures occurred in the early part of the record, from about 1939 to 1945 and again from the mid-1950s to early 1970s. An increase in temperature occurred over the historical record, however, the significance level was weak ($\alpha = \leq 0.09$). Low total annual precipitation trends are evident at both stations from about 1928 to 1940. High annual precipitation trends occurred in the early 1940s to the early 1960s and from 1981 to present. Statistical tests indicate the trend is likely true with the North Bay A station showing a $\alpha = \leq 0.01$ significance. Temperature is projected to increase by as much as 0.7 to 3.4°C in the 2020s and 3.3 to 10.6°C in the 2080s. The majority of scenarios project increased precipitation; increases as high as 20% by the 2050s and 30% by the 2080s are projected.

Lady Evelyn-Smoothwater Provincial Park (Northeast Zone)

The weather station representing Lady Evelyn-Smoothwater Provincial Park recorded cooler temperatures in the early to middle part of the 20th century, from about 1938 to 1950, and from the late 1950s to the early 1970s. The warmest MAT on record occurred from 1995 to 2003. Lady Evelyn-Smoothwater recorded the third largest increase in MAT of 1.14°C over the historical record compared to other provincial parks included in the analysis (tied with Sandbanks Provincial Park) ($\alpha = \leq 0.01$). However, TAP showed no trend. Increased temperatures of 0.6 to 2.6°C for the 2020s and 2.7 to 10.6°C for the 2080s are projected for Lady Evelyn-Smoothwater. Most scenarios project increased precipitation as high as 11% by the 2020s and 30% by the 2080s.

Sandbanks Provincial Park (Southeast Zone)

The weather station used for Sandbanks Provincial Park recorded warm periods between the late 1940s and early 1950s and from the early 1980s to 2004. Cooler temperatures prevailed in the early 1920s to about 1930 and in the late 1950s to early 1960s. Compared to other parks, Sandbanks recorded the third largest increase in MAT (tied with Lady Evelyn-Smoothwater) at 1.14°C ($\alpha = \leq 0.01$). Unfortunately, precipitation data were not available for this park. Increased temperature changes of 0.6 to 3.1°C to 2.6 to 9.4°C for the 2020s and 2080s, respectively, are projected for Sandbanks. Most scenarios project increased precipitation at Sandbanks. Increases as high as 20% by the 2050s and 30% by the 2080s may occur.

Quetico Provincial Park (Northwest Zone)

Temperature records for stations representing Quetico Provincial Park reveal three warming periods: the early 1930s, the mid 1950s to the late 1960s, and the mid 1990s to 2004. Cooler periods occurred from about 1900 to 1915 and the early to mid 1990s. Each station recorded large increases in MAT over the historical record (1.06°C for the Thunder Bay A Station, 0.98°C for the Fort Frances Station, and 0.9°C for the Mine Centre Station). All of these trends were statistically significant ($\alpha = \leq 0.05$). While little change in precipitation was recorded in the early part of the 20th century, TAP increased in the mid-1930s and declined in the late 1980s. Unfortunately, collection of precipitation data for Quetico (Thunder Bay A Station) was terminated in 1992. However, over the 97 year record, Quetico recorded the greatest increase in TAP compared to other parks (231 mm). This park is projected to experience increased temperatures ranging from 0.6 to 3.3°C in the 2020s and 2.6 to 9.8°C in the 2080s. While precipitation scenarios for the 2020s are relatively variable for Quetico, most project increased precipitation. By the 2080s, virtually all scenarios project increased precipitation with potential increases as high as 31%.

Wabakimi Provincial Park (Northwest Zone)

Wabakimi Provincial Park recorded varied temperature and precipitation patterns during the 70+ year record. Generally, cooler temperatures prevailed during the early to middle part of the 20th century while warmer temperatures prevailed from the late 1970s to the 2004. Wabakimi recorded the second greatest degree of warming compared to other parks included in the analysis (1.19°C). While TAP did increase (32.4 mm), the trend was not statistically significant and may be a result of natural variability. Temperature increases ranging from 0.7 to 3.4°C in the 2020s and 2.7 to 12.5°C in the 2080s are projected for Wabakimi. While most scenarios project increased precipitation during the 21st century, a few project decreased precipitation as well.

Lake Superior Provincial Park (Northeast Zone)

Lake Superior temperatures followed a cyclical pattern with cooler periods occurring during the 1940s, the early 1960s to 1970s, and the early 1990s, and warmer periods prevailing during the early to mid 1950s, the mid-to late 1970s, the 1980s to early 1990s, and the late 1990s to 2004. The park recorded a statistically significant ($\alpha = \leq 0.01$) temperature increase of 0.88°C over its historical record. Even though Lake Superior was the only park to experience a decrease in TAP (80 mm), the trend was not statistically significant and likely due to natural variability. Annual average temperature increases of 0.6 to 3.5°C for the 2020s and 2.7 to 10.6°C for the 2080s are projected for Lake Superior Provincial Park. While precipitation scenarios varied for the park, most project increases for the 2020s and 2050s. By the 2080s, precipitation increases are projected by all but one scenario.

Tidewater Provincial Park (Northeast Zone)

The weather station representing Tidewater Provincial Park recorded a long, cool period during the first quarter of the 21st century. A warming occurred during the middle of the century, oscillating warm and cool periods occurred between the mid 1970s and 1980s, and a significant warming period occurred from 1990 to 2004. Tidewater experienced the largest increase in MAT compared to the other parks analyzed (+1.24°C over the 119 year record) ($\alpha = \leq 0.01$). Unfortunately, precipitation data were not available for this park. Consistent with the historical warming trend, scenarios project that the temperature will increase more than in any other park in this study (0.9 to 2.9°C in the 2020s and 2.9 to 12.7°C in the 2080s). Similarly, scenarios project the greatest increase in precipitation for Tidewater. Only one scenario projects a decline in precipitation. By the 2080s, one scenario even projects that Tidewater's precipitation will increase by as much as 44%.

Step 3: Biome Type Representation Change in Ontario's Provincial Parks

As noted in Step 1, the distribution and area of terrestrial ecosystems is significantly influenced by climate, particularly temperature and precipitation (Holdridge 1947, Woodward 1987, Bailey 1996). Therefore, climate change during the 21st century will affect the composition, structure, and function of ecosystems (including biodiversity). Some species will respond to warmer temperatures by moving to more suitable habitat (e.g., habitats located in higher latitudes). However, in some cases, natural (e.g., lakes) or human-made barriers (e.g., urban areas and agriculture) will impede species movement. Underlying ecological functions (e.g., nutrient cycling and forest fire regimes) on which many species depend will be disrupted as well. Moreover, because changes in global temperature are expected to occur at a much faster rate than over the past 10,000 years, some species will not adapt in time and may disappear. Therefore, parks and other protected areas in Ontario may become unsuitable for some species currently inhabiting these areas and more suitable for invasive species that are highly adaptable and can tolerate a range of climatic and other ecological conditions.

Regardless of the general vegetation model and climate change scenario used, simulations indicate potentially significant changes in biome climate envelope (i.e., the environmental limits of an entity with a given spatial distribution by matching its known distribution to climatic surfaces) and biome representation (frequency distribution) in Ontario's provincial parks (Figs. 20-22). The MAPSS HadCM2 and UKMO scenarios project that 72 to 93% of Ontario's provincial parks will experience a change in the biome climate envelope, respectively by as early as the ~2050s (2xCO_2). The BIOME3 GVM scenario (HadCM2) projects significant change as well (64%).

The potential for change projected in this study is considerably higher than potential change described by Lemieux (2002) using an aggregated vegetation classification developed by Malcolm and Markham (2000) to asses biome climate envelop change in Ontario's parks and protected areas (Table 10). Because Lemieux's (2002) study was completed for all of Canada, a more aggregated classification system was used than necessary for this study. Accordingly, we used a more detailed vegetation classification to project vegetation climate envelope change at the provincial level.

Lemieux (2002) projected that 60% of Ontario's provincial parks would experience a change in biome climate envelope under 2xCO_2 (~2050s) under the MAPSS HadCM2 scenario, 12% less than that projected by the more detailed vegetation classification. Similarly, the UKMO scenario evaluated by Lemieux (2002) projected that 76% of Ontario provincial parks could experience a change in biome climate envelope, 16% less than that projected here. In Lemieux (2002), the 18 BIOME3 vegetation classifications were aggregated into eight classes. Under the BIOME3 HadCM2 scenario, 41% of Ontario provincial parks were projected to experience a change in biome climate envelope, 23% less than what was projected by the more detailed vegetation scenarios used in this analysis.

Overall, there was general agreement among the scenarios about the nature of the biome change (Tables 11 and 12). The GVM scenarios project that Ontario provincial parks will be subjected to more southerly biome climate envelopes, such as *tree savanna deciduous broadleaf* and *tree savanna mixed warm*. The MAPSS GVM scenario, forced by the UKMO GCM, projects that representation of the climate envelopes of these vegetation classifications

Table 10. Vegetation classifications used in this analysis compared to Lemieux (2002). The associations marked in bold font are relevant to Ontario either under current conditions or projected under the MAPSS and BIOME3 scenarios.

Biome (Base Case) (used in Lemieux 2002)	BIOME3 sub-biome types (used in this analysis)	MAPSS sub-biome types (used in this analysis)
1. Tundra	Arctic/Alpine Tundra, Polar Desert	Tundra, Ice
2. Taiga/Tundra	Boreal Deciduous Forest/Woodland	**Taiga/tundra**
3. Boreal Conifer Forest	**Boreal Evergreen Forest/Woodland**	**Forest Evergreen Needle Taiga**
4. Temperate Evergreen Forest	**Temperate/Boreal Mixed Forest**	Forest Mixed Warm Forest Evergreen Needle Maritime **Forest Evergreen Needle Continental**
5. Temperate Mixed Forest	**Temperate Conifer Forest** **Temperate Deciduous Forest**	**Forest Deciduous Broadleaf** **Forest Mixed Warm** **Forest Mixed Cool** **Forest Hardwood Cool**
6. Tropical Broadleaf Forest	Tropical Seasonal Forest, Tropical Rain Forest	Forest Evergreen Broadleaf Tropical
7. Savanna/Woodland	Temperate Broad-Leaved Evergreen Forest Tropical Deciduous Dorest Moist Savannas Tall Grassland Xeric Woodlands/Scrub	Forest Seasonal Tropical Forest Savanna Dry Tropical **Tree Savanna Deciduous Broadleaf** **Tree Savanna Mixed Warm** Tree Savanna Mixed Cool Tree Savanna Evergreen Needle Maritime **Tree Savanna Evergreen** Needle Continental Tree Savanna PJ Continental Tree Savanna PJ Maritime Tree Savanna PJ Xeric Continental
8. Shrub/Woodland	Short Grassland	Tree Savanna PJ Xeric Continental Chaparral Open Shrubland No Grass Broadleaf Shrub Savanna Mixed Warm Shrub Savanna Mixed Cool Shrub Savanna Evergreen Micro Shrub Savanna SubTropical Mixed Shrubland SubTropical Xeromorphic Shrubland SubTropical Mediterranean Shrubland Temperate Conifer Shrubland Temperate Xeromorphic Conifer Grass Semi-desert C3 Grass Semi-desert C3/C4
9. Grassland	Dry Savannas Arid Shrubland/Steppe	Grass Semi-desert C3/C4 Grassland Semi Desert Grass Northern Mixed Tall C3 Grass Prairie Tall C4 Grass Northern Mixed Mid C3 Grass Southern Mixed Mid C4 Grass Dry Mixed Short C3 Grass Prairie Short C4 Grass Northern Tall C3 Grass Northern Mid C3 Grass Dry Short C3 Grass Tall C3 Grass Mid C3 Grass Short C3 Grass Tall C3/C4 Grass Mid C3/C4 Grass Short C3/C4 Grass Tall C4 Grass Mid C4 Grass Short C4
10. Arid Lands	Desert	Shrub Savanna Tropical Shrub Savanna Mixed Warm Grass Semi-desert C4 Desert Boreal Desert Temperate Desert Subtropical Desert Tropical Desert Extreme

will increase in as many as 15 (*tree savanna deciduous broadleaf*) and 41 (*tree savanna mixed warm*) provincial parks. Conversely, more northerly biome climate envelopes, such as *forest mixed cool, forest evergreen needle-taiga*, and *forest evergreen needle continental*, are projected to significantly decrease in area in Ontario. Under the MAPSS HadCM2 and MAPSS UKMO scenarios, the *forest evergreen needle-taiga* biome climate envelope is projected to virtually disappear from Ontario's provincial parks. Similarly, both scenarios project a complete loss of the *forest evergreen continental needle* biome climate envelope.

Table 11. Biome climate envelope representation change of Ontario provincial parks based on MAPSS biomes [(by number of park geocentroids and percent (%)].

Classification	Climate Model				
	MAPSS current	HadCM2 ($2xCO_2$)	HadCM2 change	UKMO ($2xCO_2$)	UKMO change
Water/Error	28	28	n/c	24	-4 (-14.2%)
Forest Deciduous Broadleaf	36	37	+1 (+2.7%)	153	+117 (+325%)
Forest Mixed Warm (DEB)	0	0	n/c	15	+15 (na)
Forest Mixed Cool	95	101	+6 (+6.3%)	1	-94 (-98.9%)
Forest Evergreen Needle Taiga	73	6	-67 (-91.7%)	0	-73 (-100%)
Forest Evergreen Needle Continental	20	0	-20 (-100%)	0	-20 (-100%)
Forest Hardwood Cool	0	81	+81 (+8,100%)	0	n/c
Tree Savanna Deciduous Broadleaf	0	0	n/c	15	+15 (n/a)
Tree Savanna Mixed Warm (DEB)	0	0	n/c	41	+41 (n/a)
Tree Savanna Evergreen Needle Continental	0	0	n/c	4	+4 (n/a)
Taiga/Tundra	1	0	-1 (-100%)	0	-1 (-100%)

n/c= no change
n/a= not applicable

Table 12. Biome climate envelope representation change of Ontario provincial parks by BIOME3 biomes [(by number of park geocentroids and percent (%)].

Classification	Climate Model		
	BIOME3 current	HadCM2 ($2xCO_2$)	HadCM2 change
Water/Error	40	32	-8 (-20.0%)
Boreal evergreen forest/woodland	29	1	-28 (-96.6%)
Temperate conifer forest	125	101	-24 (-19.2%)
Temperate/boreal mixed forest	32	0	-32 (-100%)
Temperate deciduous forest	27	119	92 (+340.7%)

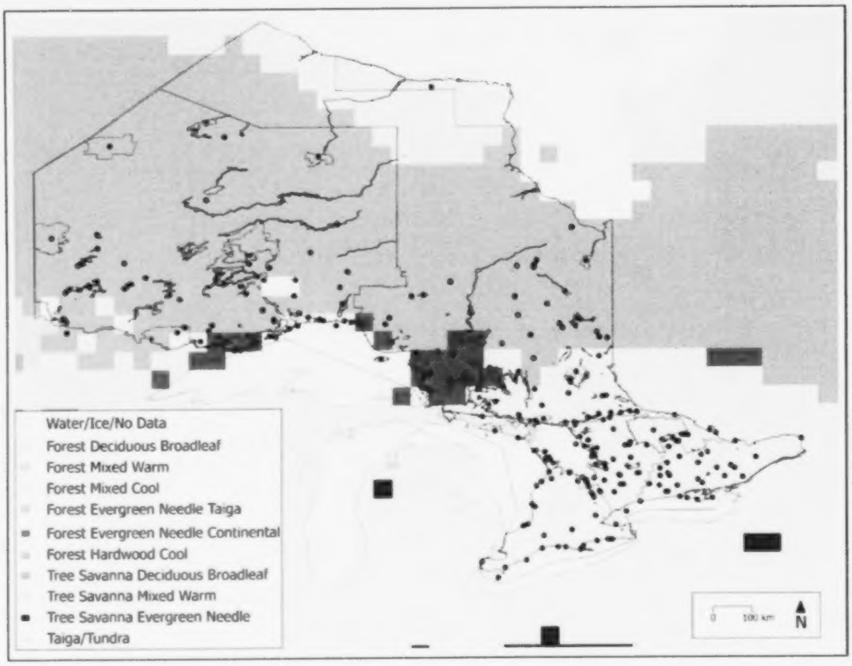


Figure 20. Geocentroids of Ontario's provincial parks (black circles) and current distribution of biome climate envelopes in Ontario simulated by the MAPSS (Mapped Atmosphere-Plant-Soil System) baseline scenario.

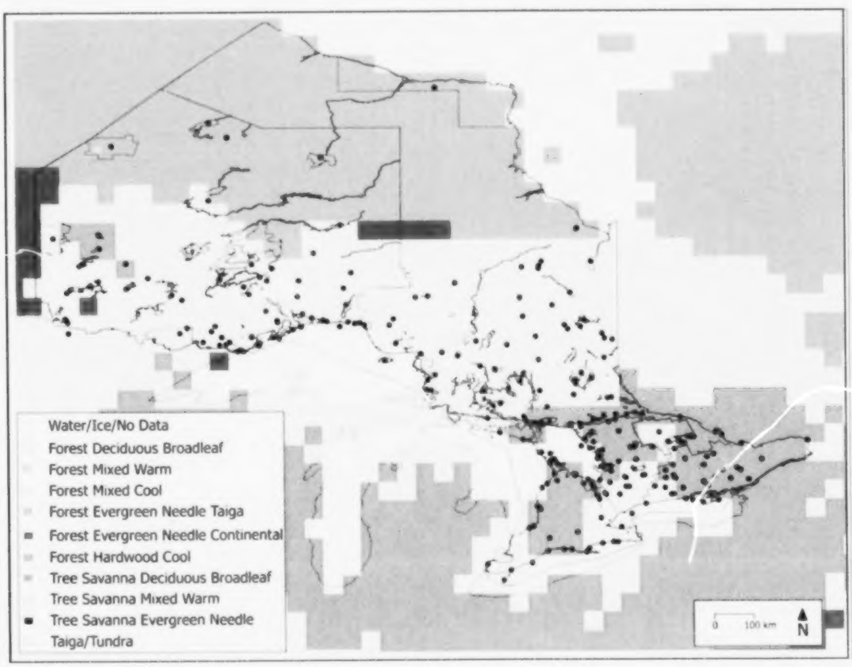


Figure 21. Geocentroids of Ontario's provincial parks (black circles) and biome climate envelope change simulated by the MAPSS HadCM2 (Mapped Atmosphere-Plant-Soil System Hadley Centre Global Circulation Model) scenario.

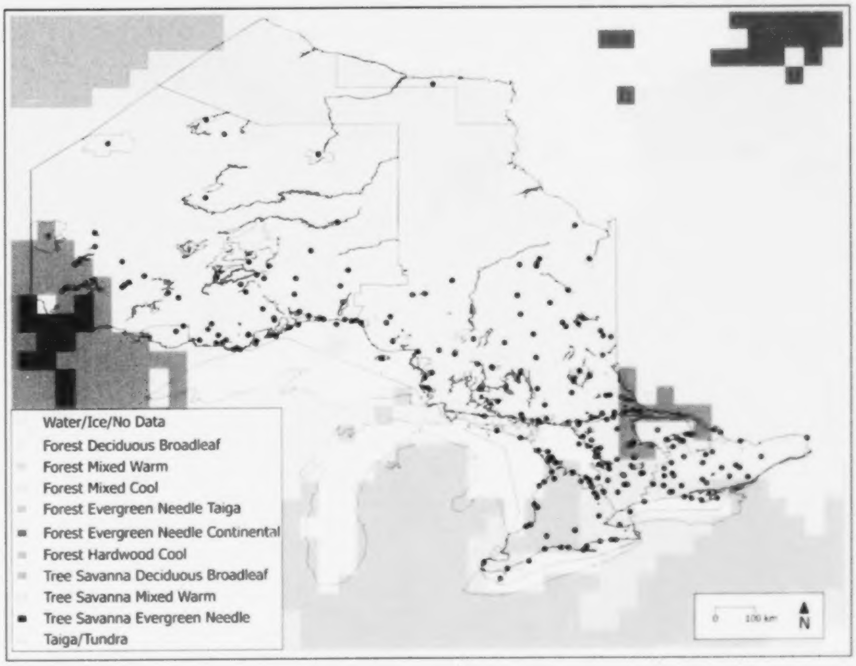


Figure 22. Geocentriods of Ontario's provincial parks (black circles) and biome climate envelope change simulated by the MAPSS UKMO (Mapped Atmosphere-Plant-Soil System United Kingdom Meteorological Office Global Circulation Model) scenario.

While both MAPSS scenarios (HadCM2 and UKMO) project similar changes in biome climate envelope representation for Ontario provincial parks, there are some differences. For example, where the HadCM2 scenario projects a small increase in the *forest mixed cool* biome climate envelope representation (+6%), the UKMO scenario projects a significant decrease (-94%) under 2xCO_2 (~2050s).

The BIOME3 HadCM2 scenario and the MAPSS HadCM2 scenario project similar changes in biome climate envelope representation, although it is important to remember that the comparative analysis is limited because different classification schemes were used to generate both GVMs (Tables 11 and 12). Generally, the BIOME3 HadCM2 scenario projects the loss of all northern biome climate envelopes, including the *boreal evergreen forest/woodland* biome climate envelope (-96.6%) and projects significant expansion of the *temperate deciduous forest* biome climate envelope into Ontario's provincial parks (an increase in representation in 92 provincial parks) (Table 12). Under all GVM and GCM scenarios, the only provincial park currently located in the *taiga/tundra* biome climate envelope (Polar Bear Provincial Park) is projected to be completely encompassed by a new biome climate envelope.

Step 4: Climate Change and Fire Severity in Ontario's Provincial Parks

Climate Change, Protected Areas, and Fire Management in Ontario

Fire is an important driver for maintaining and enhancing ecosystems in many provincial parks and conservation reserves, ranging from boreal forest ecosystems in northern Ontario to threatened tallgrass prairie and oak savannah ecosystems in southern Ontario. Accordingly, OMNR staff in several Ontario provincial parks have prepared fire management plans [e.g., *Pinery Provincial Park Resource Management Strategy* (OMNR 1988), *Quetico Provincial Park Fire Management Plan* (OMNR 1997), and *Rondeau Provincial Park Vegetation Management Plan* (OMNR 2001)] to ensure that representative examples of fire-dependent species and ecosystems are maintained, and additional plans are in preparation.

Ontario Parks and the Ontario Ministry of Natural Resources (OMNR) fire program work together to conduct prescribed burns each year and implement monitoring programs to track vegetation response. Further, the OMNR recently completed the *Fire Management Policy for Provincial Parks and Conservation Reserves* (OMNR 2004a), which was favourably reviewed in the *Environmental Commissioner of Ontario's 2004-2005 Annual Report* [Environmental Commissioner of Ontario (ECO) (2005)].

Under changing climatic conditions, natural resource managers may find it increasingly difficult to achieve a balance between protecting socio-economic values (such as property and human health), protecting natural values (such as rare or endangered species), and promoting the use of fire in restoring and maintaining ecosystem health and representation in Ontario's protected areas. Weber and Flannigan (1997) state that "*...fire regime as an ecosystem process is highly sensitive to climate change because fire behavior responds immediately to fuel moisture and that interaction between climate change and fire regime has the potential to overshadow the direct effects of global warming on species distribution, migration, substitution, and extinction.*" This statement suggests that changes in fire will be one of the most important climate change issues facing parks and protected area managers during the 21st century.

Forest management decisions made today are based on the assumption that climate will remain relatively stable throughout the life of the trees in the ecosystem (Spittlehouse and Stewart 2003). While this approach may have worked in the past, it will not work in the future – climate change will alter forest dynamics and forest managers will need to anticipate these changes and prepare to adapt management programs to them. A number of climate change and forest fire modelling studies suggest that Canada will experience increases in forest fire activity under a warmer, and in some areas, drier climate (e.g., Stocks 1993).

In one of the first studies of its kind, Flannigan and Van Wagner (1991) used three GCMs to compare seasonal fire severity under a warmer climate based on doubled-CO_2 with historical climate records and estimated that fire severity could increase by as much as 50% across Canada. Wotton and Flannigan (1993) used the Canadian GCM to project fire season length across Canada under climate change, and showed that fire season length in Canada could increase by as much as 30 days under a doubled-CO_2 climate. Flannigan *et al.* (2005) used historical relationships between weather/fire danger and area burned in tandem with two GCMs to estimate future area burned in Canada. The results suggest an increase of 74–118% increase in area burned by the end of the 21st century.

Fosberg *et al.* (1990) found that a significant increase in the geographical expanse of the highest fire severity conditions is projected across Canada and Russia under a warming climate. According to Zimov *et al.* (1999), fire disturbance in the circumpolar boreal forest increased by approximately 250% in the 1980–1990s when compared to the 1950–1960s (Stocks *et al.* 1998). Stocks *et al.* (2000) reported that fire activity has been increasing over the past three decades in Canada, burning an average of 3 million ha annually since 1980. Since the early 1960s, the fire season length has increased by as much as eight days in parts of northwestern Ontario along the Manitoba border (McAlpine, OMNR, SSM, pers comm 2006).

Wotton *et al.* (2005) examine climate change and the future fire environment in Ontario, and project that the total number of fires occurring in Ontario's fire management area will increase 15% by 2040 and 50% by the end of the century. Moreover, the authors project that the higher fire occurrence is expected to "*...increase the cost of fire management in the province 16% by the year 2040 and 54% by the year 2090 over year 2000 costs, exclusive of inflation or other factors*" (Wotton *et al.* 2005: 3).

In addition to developing a baseline description of fire severity for 1980 to 1989 (Fig. 23), we prepared a doubled-CO_2 scenario for 2050 (Fig. 24), and a tripled-CO_2 scenario for 2090 (Fig. 25). In general, the *low* and *moderate* fire severity rankings will decrease and the *high*, *very high*, and *severe* fire severity rankings will increase for the majority of Ontario's provincial parks under the 2050 (doubled-CO_2) and the 2090 (tripled-CO_2) scenarios (Fig. 26). The fire severity index is relative, with values above 6 being extreme and a value of 0 only possible in remote cold regions where no fire danger exists in the summer months. The higher the fire severity ranking, the greater potential there is for more frequent and severe fires and an increase in geographical extent (i.e., area burned).

Forest fire severity in Ontario's provincial parks is projected to increase considerably by mid-century as a result of the expanded geographical extent of larger, more widespread, and more severe fires (>4 fire severity ranking). For example, during the 1980 to 1989 baseline, 58% of Ontario's provincial parks were classified within the *low* and *moderate* (<2) fire severity rankings. By 2050 and 2090, only 43% and 26% of Ontario's provincial parks are projected to be classified within the *low* and *moderate* (<2) fire severity rankings, respectively. During the 1980 to 1989 baseline period, only 3% of Ontario's provincial parks fell into the *extreme* (>6) fire severity ranking range. In the 2050s and 2090s scenarios, however, the number of provincial parks with *extreme* fire severity ratings increases considerably. For example, by the 2050s, 10% of Ontario's provincial parks will fall within the *extreme* forest fire severity ranking. By 2090, this number is projected to increase to 21% vs. 3% in the 1980-1989 baseline period.

Southern Ontario has many relatively small provincial parks that are rarely subjected to natural wildfire. And because our project uses the number of parks and not area, a regional bias occurs in our analysis – a relatively high percentage of provincial parks used in this analysis are projected to experience *low* to *moderate* levels (<2) of fire severity under both the doubled-CO_2 (39%) and tripled-CO_2 (23%) scenarios. However, *extreme* fire conditions are also projected for parks north of 46°N latitude, especially in the northwest. Because parks in the Northwest Zone are relatively few in number but much larger in size, the results in this analysis do not adequately reflect the potential for an increase in total "area" burned. Despite the relatively high fire severity rankings projected for parks south of 46°N, wildfires in these forests will continue to be small under a warmer climate, a reflection of fragmentation and relatively small patches of continuous fuels in forests, savannahs, and prairies.

Figure 23. Fire severity map for Ontario: 1980–1990 (baseline).

Figure 24. Fire severity projected for Ontario for 2050-2059 based on approximate doubling of CO_2.

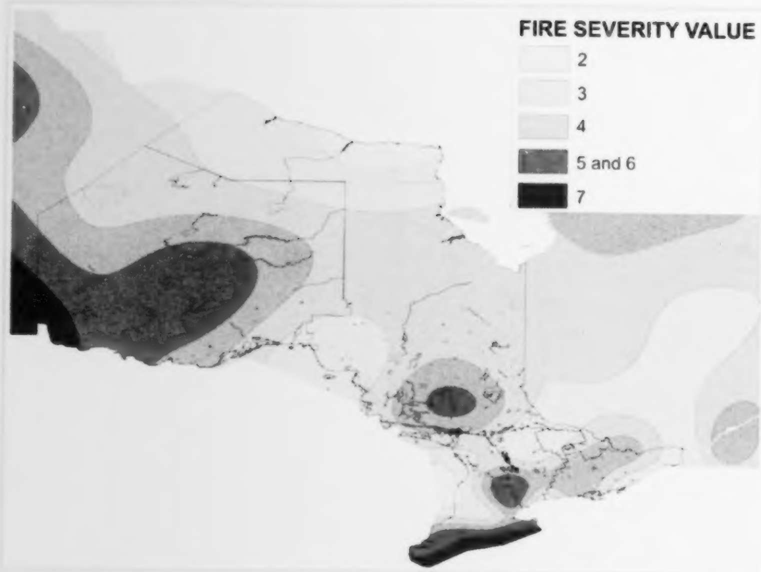


Figure 25. Fire severity projected for Ontario for 2090–2099 based on approximate tripling of CO_2

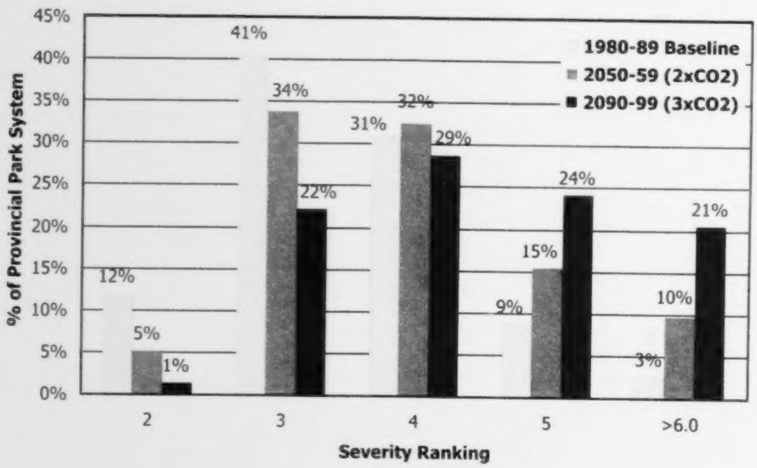


Figure 26. Change in fire severity rankings in Ontario from the 1980–1990 baseline period to the 2050s (approximate doubling of CO_2) and 2090s (approximate tripling of CO_2), using the Canadian Global Circulation Model Second Generation†.*

† Low severity ranking = <1.0, Moderate severity ranking = 2-3; High and Very High severity ranking = 4-5; Severe severity ranking = >6.* Percentages may not add up due to rounding and omission of geocentroids falling on water.

Implications of Climate Change and Forest Fire Activity for Ontario's Provincial Parks

Given the values at risk resulting from climate change (e.g., public safety, capital assets within and adjacent to protected areas, timber values adjacent to protected areas, and species and their habitats), projected increases in area burned and fire abundance will require a continued, and in some areas, an increased commitment to fire management. Recognizing that many ecosystems within Ontario's parks require fire disturbance for natural renewal and that these fire-dependent ecosystems will not continue to represent the natural heritage they are designed to protect unless exposed to fire, the OMNR has recently initiated research on the role of fire in several parks. Results of this research will be used to develop policy and planning tools to support the safe and effective reintroduction of fire in provincial parks and conservation reserves (Davis *et al.* 2004). OMNR has also prepared a new *Forest Fire Management Strategy for Ontario* (OMNR 2004b) with the following management objectives and direction for 11 large protected areas included in the Parks Fire Management Zone:

"Management objectives:

- Protect park visitors and prevent socio-economic disruption.
- Enable the ecological role of fire as an agent of disturbance for the maintenance of ecosystems and critical habitat.
- Promote a "naturalness" objective to approximate a natural forest and wildlife habitat condition.
- Minimize loss or damage to provincial park property, infrastructure and structures.
- Minimize impacts of prescribed fire programs on adjacent land users and communities through proper planning and sound decision-making.

Management direction:

- Fires within the parks zone will be actioned in response to approved park fire management plans or interim fire response strategies.
- "Light-on-the-Land" fire suppression techniques will be used, wherever feasible, when protecting sensitive features.
- Fires that threaten park visitor safety or park infrastructure will be managed using a "Full Response" and sustained action until extinguished.
- Fire Management Plans will be developed for each Park in the Parks Zone subject to available park resources.
- A fire management plan for Quetico Provincial Park has been developed and provides direction for fire management activities within the park.
- Prescribed burning is recognized as a management tool to meet ecosystem management or hazard reduction objectives within this zone. Proponents are encouraged to utilize prescribed burning to meet management objectives."

Under changing climatic conditions and associated increased fire severity, natural resource managers will find it increasingly difficult to achieve a balance between protecting socio-economic values (e.g., human safety and property), protecting natural values (e.g., rare or endangered species and ecosystems), and promoting the use of fire to restore and maintain the health of ecosystems represented in Ontario's parks. For example, in addition to preventing property loss and threats to human health, Spittlehouse and Stewart (2003) emphasize that a high priority for forest managers under a changing climate will be their ability to cope with and adapt to forest disturbance while maintaining genetic diversity and resilience of forest ecosystems.

Spittlehouse and Stewart (2003) developed a four-step forestry adaptation framework for natural resource management in a changed climate: (1) define the issue (e.g., effects of warmer annual and drier summer conditions on tree growth), (2) assess the vulnerability of the forest to change (e.g., increased disturbance through fire), (3) identify steps that can be taken now (e.g., include climate variables in growth and yield models) to reduce vulnerability to climate change, and (4) identify steps that can be taken in the future (e.g., plant alternative genotypes or different species).

There are many ecological implications to increased fire disturbance. For example, because many organisms and ecosystems depend on fire, an increase in forest fire frequency and distribution could mean an increase in representation of species that depend on fire for renewal, such as red oak (*Quercus rubra*) and eastern white pine (*Pinus strobus*). Moreover, species that favour open habitats created by fire could respond favourably to increased fire as well. Increased fire disturbance may help to maintain rare natural prairie and savannah ecosystems as well.

Increased forest fire activity will require park managers to adapt their management programs. For example, increased risk of fire may increase the number of campfire bans, trail and area closures, investments in forest fire management supplies and equipment, and expenditures related to clean-up activities, such as erosion control and hazard reduction in burned areas.

The regional variation depicted in the climate change scenarios suggest that increased forest fire severity will vary by fire management zone[3]. It is also anticipated that OMNR will need to reconcile differences between policy designed to maintain ecosystem composition, structure, and function in a fire-driven landscape and socio-economic considerations related to human safety and property and commercial value of the forest. Accordingly, adaptive management will be critical. Forest and protected area managers must acknowledge that climate change will affect protected areas, forests, and other ecosystems such as wetlands.

As Spittlehouse and Stewart (2003: 2) emphasize, *"Even without a clear view of the future climate and forest, it is possible to develop adaptation strategies now."* Incorporating climate change into OMNR's fire management strategy (OMNR 2004b) and the *Fire Management Policy for Provincial Parks and Conservation Reserves* (OMNR 2004a) will enable improved response to potential long-term impacts of fire activity in Ontario's provincial parks. A likely response could involve restructuring site-specific priorities to support more intensive protection of smaller, high-value areas, and a return to natural fire regimes over larger areas of Ontario (OMNR 2004b). Other related questions requiring deliberation include: What future research is needed to aid in the development of appropriate adaptive strategies? What management options are required or already available to reduce risk? What are the barriers to implementing these management options and adaptive strategies? Which species will adapt naturally and which species might require active management (e.g., translocation)?

Adaptation to climate change in forest and protected areas management requires a planned response well in advance of some climate change impacts because of the long-term and dynamic planning horizons required by these sectors (e.g., 50+ years). Spittlehouse and Stewart (2003) emphasize that an effective adaptive policy must be responsive to a variety of economic, social, political, and environmental circumstances. Acknowledging the impacts of climate change on provincial park ecosystems and incorporating management options into the fire strategy (OMNR 2004b), the *Fire Management Policy for Provincial Parks and Conservation Reserves* (OMNR 2004a), and ensuing fire management planning direction are important first steps towards a process designed to adapt to climate change.

Step 5: Implications for Ontario Parks' Planning, Policy and Management Frameworks

Ontario Parks System Planning and the Ecological Representation Principle

Ontario's first provincial parks, Algonquin (1893) and Rondeau (1894), were established to provide recreational, medicinal, spiritual, and economic benefits. At the time, the protection of natural heritage features was perceived as a secondary benefit. During the first half of the 20th century protected areas were established for many, often unrelated reasons (Gray *et al.* in prep). In fact, systematic protected area planning was not introduced as a planning tool until the mid-20th century in North America and was largely the result of the creation of the United Nations International Biological Programme (IBP) in 1963. Once established, the IBP surveyed for the protection of *"representative habitats"* around the world. By the time it ended in 1974, IBP volunteers had inventoried 1,651 areas in Canada including 618 sites in Ontario (OMNR 1981). The collaboration between the OMNR and the IBP significantly influenced Ontario Parks' policy development in the 1960s and 1970s.

In 1961, the Department of Lands and Forests (now OMNR) established a Nature Reserves Committee to select areas representative of Ontario's site regions. This program complemented the goal of the IBP and in 196[illegible] the Parks Branch introduced a parks classification system that recognized the need to protect unique and representative natural features for the purpose of public education and scientific study (Parks Branch 1967) (Table 13). The Nature Reserves Committee concluded that the site region framework (ecosystem classification) developed by Angus Hills (1960, 1961) be adopted as the ecological context within which to create a representative natural heritage system.

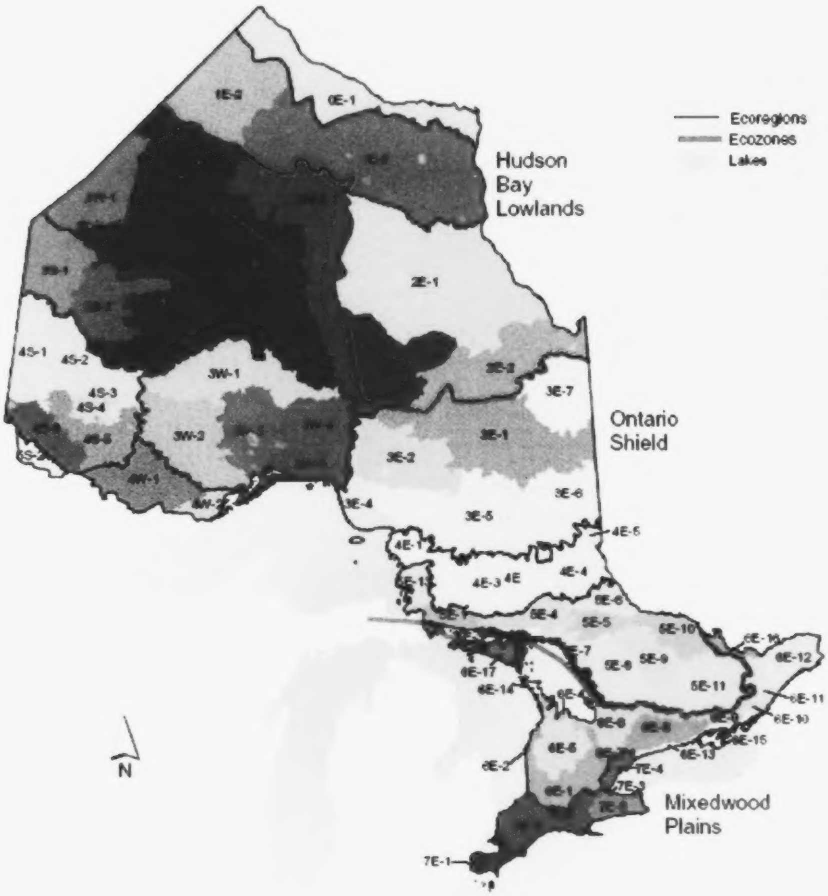
[3] Fire management zones are defined in OMNR's *Forest Fire Management Strategy* (OMNR 2004b) for Ontario as areas with broadly common land use, resource management and fire management objectives. The *Forest Fire Management Strategy* for Ontario defines six fire management zones: Southern Ontario; Parks; Great Lakes/St. Lawrence; Boreal; Northern Boreal; and Hudson Bay.

Figure 27. Ecozones, ecoregions, and ecodistricts of Ontario (Crins 2002).

Hills' (1960, 1961) ecosystem classification system was based on climatic, geological, and physiographic patterns which were used to delineate site regions and site districts (now called ecoregions and ecodistricts). The classification was designed to provide information on the biological and physical characteristics of areas to help assess ecosystem productivity (for forests, wildlife, water) and the likely responses to land-use impacts (e.g., engineering works, resources extraction, and fire).

Hills (1961) recognized the fundamental importance of climate in the formation of forested ecosystems and used "normal" reference points and "uniform" or "homogeneous" features to develop vegetation descriptions for each region. Hills (1960: 417) defined ecoregions as *"having a definite pattern of vegetation"* and boundary delineation was based on temperature and humidity. Although the objective of the research was initially oriented to a description, classification, mapping, and evaluation of land in Ontario for forest productivity, the scheme was applied to other natural resource management disciplines including protected areas management during the latter part of the 20th century.

The 14 ecoregions and 71 ecodistricts currently used by Ontario Parks (Fig. 27) to establish the geographical context for representation still largely reflects the work done by Hills (1960, 1961). Some modifications and adjustments to the boundaries have been made in recent years, a result of evolving rationales, new techniques, and improved inventories of Ontario's natural features (Crins 2002, Davis and McCalden 2004, Crins *et al.* in prep.).



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The 1967 park classification described five park classes (i.e., Primitive, Nature Reserve, Wild River, Natural Environment, and Recreation) and four zones (i.e., Natural, Primitive, Recreational, Historic and Multiple-Use). This initial park classification system fostered a more structured and systematic approach to the designation, planning, and development of parks than had been used in the past. Ultimately, the park classification and zoning system recognized provincially significant natural and cultural features and provided a management framework to represent and protect these features.

During the late 1970s and early 1980s, inventories were completed to determine the extent to which existing provincial parks achieved the required representation (OMNR 1977). The 1977 document entitled *Ontario Provincial Parks: A Proposed Policy* states that "*Ontario Provincial Parks are established to secure for posterity representative features of Ontario's natural and cultural heritage. Wherever possible, the best representations of our heritage will be included in the parks system.*" This objective was incorporated into official park policy in 1978 (OMNR 1978).

In the 1980s and 1990s, Ontario Parks completed a number of studies to assess the biophysiographic representation provided by parks, recommended parks, and other protected areas in Ontario (e.g., Beechey and Davidson 1980, Noble 1986). The concept of earth science and life science representation also guided the establishment of Areas of Natural and Scientific Interest (ANSIs), which were used by the OMNR as a tool to "flag" special sites on publicly or privately owned areas of land and water with important natural heritage, scientific, or educational values. ANSIs were identified with the same earth science and life science criteria used to help identify and select provincial parks and, more recently, conservation reserves.

Table 13. Goals and objectives of the 1967 parks classification scheme (Parks Branch 1967).

Goal/Objectives	Statement
Goal	To develop a framework that will facilitate the identification and protection of representative examples of Ontario's native ecosystems and biota.
Objectives	To present a methodology for the identification, description, and selection of representative examples of ecosystems and biota native to Ontario. To identify reserve design and management considerations to ensure the long term protection of contained natural features. To explore the institutional arrangements for the protection and maintenance of ecosystems and biota.

Table 14. Objectives for Nature Reserve, Natural Environment, and Waterway class parks (Government of Ontario 2006).

Park Classification	Objective
Nature Reserve Class Parks	Protect representative ecosystems and provincially significant elements of Ontario's natural heritage, including distinctive natural habitats and landforms, for their intrinsic value, to support scientific research and to maintain biodiversity.
Natural Environment Class Parks	Protect outstanding recreational landscapes, representative ecosystems and provincially significant elements of Ontario's natural and cultural heritage and to provide high quality recreational and educational experiences.
Waterway Class Parks	Protect recreational water routes and representative and significant terrestrial and aquatic ecosystems and associated natural and cultural features and to provide high quality recreational and educational experiences.

The current planning and management policy (often referred to as the *Blue Book*) used by Ontario Parks provides for the protection of key natural, cultural, and recreational resources where "*provincial parks are established to ensure that features representing the most significant aspects of Ontario's natural and social history are protected, now and in the future*" (OMNR 1992b: 2). Representation is one of the principles used to guide the management of the Ontario provincial park system (in addition to the principles of permanence, distinctiveness, variety, accessibility, coordination, system, and classification), and contributes to the achievement of parks program objectives (OMNR 1992b). The *Blue Book* states that "*Provincial Parks are established to secure for posterity representative features of Ontario's natural and cultural heritage. Wherever possible the best representations of our heritage will be included in the park system*" (OMNR 1992b: 13). Three classification schemes – one each for life science, earth science, and cultural resources – form the basis for provincial park representation requirements in Ontario (OMNR 1992b: 12). Ontario Parks uses representation to take a balanced approach to systematically identify and protect Ontario's life science, geological, and cultural features – an approach supported by Ontario's Provincial Auditor, Environmental Commissioner, and elected officials (Davis and McCalden 2004).

The Provincial Park classification described in the 1978 policy was modified to include Wilderness, Nature Reserve, Historical, Natural Environment, Waterway, and Recreation class parks and Wilderness, Nature Reserve, Natural Environment, Historical, Access, Development, and Recreation/Utilization zones in the *Blue Book* (OMNR 1992b). Representation is used to guide the establishment of Nature Reserves, Natural Environment and Waterway class parks as described in the *Blue Book* and the recently passed *Provincial Parks and Conservation Reserve Act* (Government of Ontario 2006) (Table 14).

OMNR's current life science representation thresholds stipulate that for each landform-vegetation association, at least 1% of its total area in an ecodistrict or 50 ha (whichever is greater) should be included within protected areas. 'Gap analysis' is used to identify all occurrences of under-represented landform-vegetation associations. In most cases, only some of these occurrences need to be included within protected areas to meet the minimum representation thresholds (Davis and McCalden 2004).

Implications of Climate Change for Ontario Parks' System Planning, Policy and Management Frameworks

Climate Change and Ontario Parks System Planning: Emerging Issues

Like the current Canadian national park system plan, Ontario's provincial protected areas system planning assumes a stable climate. Given that Ontario's climate is rapidly changing and is no longer "stable" in the context of the traditional definition, the known and potential impacts of climate change have important implications for 21st century Ontario Parks' policy, planning, and management programs. Similar to other parks and protected area agencies around the world, Ontario Parks uses "ecological representation" as an important criterion in park system planning. Accordingly, it is assumed that the completed protected areas network will represent Ontario's biodiversity and promote its persistance through time. As previously noted, Hills (1960, 1961), Crins (2002), and Crins *et al.* (in press) recognize the fundamental importance of climate in the classification of forest sites and used "normal" reference points to describe vegetation in each site region or ecoregion.

Climate change requires that park and protected area managers address a number of questions, including, but not limited to:

- How should protected area system planners address representation in a rapidly changing climate?
- What is a representative natural area in a rapidly changing climate? An area protected to ensure that natural climate-driven ecological change can occur?
- Given that new, presently unknown species assemblages may result from climate change, is there need for policy discussions about the definition of invasive/alien species during a time of rapid climate change?

The implications of climate change for conservation theory are complex and require ongoing analyses. For example, the Ontario Parks principles of "permanence" and "system" do not account for climate change, and some objectives at the provincial parks system and park level may lose their relevance as ecosystems change. Accordingly, we anticipate that future park system planning will need to account for ecosystem dynamics and address climate change.

Climate Change and Ontario Provincial Park Management Plans

Provincial park management plans are prepared for each park in accordance with the *Provincial Park Management Planning Manual* (1992b). Given that ecosystems and species will respond uniquely to climate change in each park, adaptation may need to be considered in each park management plan.

Each provincial park is designated to protect ecosystems representative of the natural region within which it is located. The management plan for each park defines the purpose of the park. For example, the Killarney Provincial Park Management Plan (OMNR 1986) states that, "*The park will protect a representative portion and modern environments associated with La Cloche Mountains.*" Similarly, the Quetico Provincial Park Management Plan states that "*Quetico Provincial Park will protect a representative portion of the ancient geological history, modern biological environments, and cultural features associated with site region 4W*" (OMNR 1995a, emphasis added). The emphasis on the protection of "modern" biological environments implies that management plans must address the changing distribution and abundance of organisms.

In some cases, ecological change may be so significant that a park no longer represents the values for which it was originally established. For example, Polar Bear Provincial Park was established to protect one of the world's largest denning areas for polar bears (*Ursus maritimus*). Under climate and vegetation change scenarios and with reduced ice-cover in Hudson and James Bay, polar bears may be forced northward in search of more suitable habitat and where they can more effectively hunt ringed seal (*Phoca hispida*). Under these scenarios, Polar Bear Provincial Park may no longer contain important habitat for polar bears. Similarly, changing climate, vegetation, and fire conditions in northwestern Ontario may change the distribution of woodland caribou (*Rangifer tarandus*) habitat. Parks such as Woodland Caribou, which were specifically established to protect keystone species, may not meet protection objectives in a rapidly changing climate. However, these protected areas will encompass new, evolving ecosystems that will probably 'represent' change in the ecodistrict and/or ecoregion.

The objective of Pinery Provincial Park is "*...to protect an extensive, provincially significant, freshwater dune system with associated representative floral, faunal and cultural features and to provide high quality educational and recreational experiences*" (OMNR, 1988: 1). Moreover, The Pinery Provincial Park Management Plan states that the park will "*...ensure that Pinery harbours the richest naturally occurring communities inherent to its unique microclimate and topography*" (OMNR 1988: 4, emphasis added). What is considered "natural" will become more difficult to define as the ranges of species change. New species, currently regarded as "non-native", may find suitable refuge within The Pinery. In these cases, the ecological manifestations of climate change may be such that the established management objectives of the park will require re-assessment.

From a species conservation perspective, perhaps most important are the potential effects that climate change poses for vulnerable, threatened, and/or endangered species inhabiting Ontario provincial parks. Many of these species [e.g., eastern foxsnake (*Elaphe gloydi*)] have very specific habitat requirements or are limited by habitat availability, and are vulnerable to change. Without active intervention (e.g., translocation where appropriate and where feasible), provincially significant species may be lost. Conversely, warmer climates may increase available habitat for some species.

Other OMNR strategies, such as those designed to control invasive species, may also require re-assessment in a rapidly changing climate. For example, the *Lake Superior Provincial Park Management Plan* (OMNR 1995b) states that non-native plant species will be removed if they conflict with the representation values for which the park has been established. This statement does not provide for ecosystem change nor the changing distribution and abundance of species in response to climate change. Other policies, such as the *Fire Management Policy for Provincial Parks and Conservation Reserves* (OMNR 2004a), may also be tested for their effectiveness in re-

establishing forest species representation (one of the reasons the policy was developed) under changing climate and fire severity conditions (as discussed in more detail in Step 4).

Finally, Ontario's provincial parks are a significant resource for nature-based tourism – one of the fastest growing tourism markets in the world, especially in Canada. Climate change will alter recreational opportunities and visitation patterns in parks, which will affect local economies and potentially create a new suite of park use issues, including ecological degradation. Visitor management plans will need to be re-examined in the context of changing visitor behaviour and seasonal visitation patterns (Jones and Scott 2006). In addition to seasonality changes, as climate change affects the natural settings (e.g., special natural features and fire-disease impacted forest landscape), the quality of tourism could change in some parks, with subsequent implications for visitation to parks and local communities.

Summary Observations and Suggestions

A number of new provincial parks and conservation reserves have been established in the last 30 years through a variety of initiatives. Most recently, the 1999 *Ontario Land Use Strategy* provided for the creation of 379 new protected areas encompassing some 2.4 million hectares. In fact, between 1970 and 2000, the system of provincial parks and conservation reserves doubled in number to over 600 and protects nearly 9% of Ontario. Since 1992, Ontario has increased its protected area by 51%. Taken collectively, the provincial parks system provides the best available in-situ examples of natural and physical features in Ontario. Moreover, the provincially significant (i.e., rare) species and species at risk protected in provincial parks and conservation reserves represent a priceless legacy of heritage conservation that has been assembled over the past 100 years and has contributed to the requirements outlined in the *Statement of Commitment* (FPPC 2000), the *Convention on Biological Diversity*, the *Canadian Biodiversity Strategy*, and the *Ontario Biodiversity Strategy*. Climate change will impact park and conservation reserve protection and management programs during the 21st century and beyond.

A number of potential climate change-induced policy and management issues will require attention in the 21st century. Some of these issues are outlined below, along with general suggestions for consideration by protected areas managers:

Adaptive Management: Adaptive management may be required at all levels of planning and management in the parks and conservation reserve system. Ontario Parks could work to ensure that natural adaptation and human mediated adaptation are incorporated in policies and management plans.

System Planning: Climate change will alter the boundaries of ecosystems upon which ecological representation is based. This change will require re-assessment of system planning principles and objectives in the context of climate change.

Protected Area Networks: Protected area networks are an important part of healthy ecosystems. Ontario Parks should work to integrate climate change into protected areas site selection criteria, examine options for enhancing connected networks of protected areas, and improve collaboration with Ontario's many agencies and organizations on the issue of climate change.

Managed Landscapes: The role and importance of some ecosystems in providing habitat for plants and animals will change with rapid climate change. Ontario Parks could work to incorporate species-climate dynamics into gap analyses, site selection strategies, and employ an ecosystem approach to management.

Protected Areas Habitat: Habitats located inside some protected areas may no longer be accessible to species that depend on them. For example, some species may lose the ability to physically access traditional habitat or may lose the ability to physiologically or phenologically respond to new, emerging climate regimes in the protected area. Protected area managers may need to develop species response protocols designed to help them determine if active management intervention is warranted and appropriate.

Invasive Species: Some species from other ecosystems likely will find and occupy ecological niches in existing protected areas in a changed climate. Given that their response (e.g., altered range) is natural, should we consider

them invasive? Protected area managers may want to work with managers in other natural resource disciplines to examine current definitions and re-assess policy and management approaches to invasive species in a changing climate.

Recreation and Tourism Resources: The availability of some recreational activities will decline while new opportunities will emerge. How should Ontario Parks begin to address this issue, especially as it relates to visitor management plans? Protected area managers may need to analyze potential climate change impacts on tourism and recreation patterns, revenue, and local economies on an ongoing basis and adjust policies and programs accordingly.

Fire Planning and Management: Many ecosystems within Ontario's protected areas depend on fire for renewal. However, under changing climatic conditions, natural resource managers may find it increasingly difficult to achieve a balance between protecting socio-economic values (e.g., property and human health), protecting representative natural values (e.g., rare or endangered species and ecosystems), and promoting the use of fire in restoring and maintaining ecosystem health in Ontario's protected areas. Protected area managers should assess and modify fire management and prescribed burning programs in the context of climate change as required.

Monitoring and Reporting: Long-term monitoring and reporting is necessary to plan and manage for climate change. Ontario Parks should consider establishing a program for ecological inventory, monitoring, and reporting (including the establishment of a sophisticated weather monitoring network) that enables protected area managers to effectively assess ongoing and emerging impacts of climate change.

Moving Forward

Although there is much uncertainty over the timing, extent, and manner in which park ecosystems and their species will respond to new climatic conditions, it is still important to identify and assess adaptation strategies that might reduce their vulnerability. Partnership, corporate culture and function, financial commitment, data and information management, research, well trained staff and partners, and communication are essential to successfully adapting Ontario's system of protected areas to climate change.

References

Bailey, R.G. 1996. Ecosystem Geography. Springer-Verlag, New York, NY.

Beechey, T. and R.J. Davidson. 1980. Protection of significant natural areas: The nature reserves system. Ontario Ministry of Natural Resources, Toronto, ON.

Boer, G.J., N. McFarlane and M. Lazare. 1992. Greenhouse gas induced climate change simulations with the CCC second generation GCM. Journal of Climatology 5: 1045-1077.

Burns, C.E., K.M. Johnston and O.J. Schmitz. 2003. Global climate change and mammalian species diversity in US national parks. Proceedings of the National Academy of Sciences 100 (20): 11474-11477.

Byrne, M-L, D. Woods and A. Maclean. 2004. Water level changes and sand transport at Pinery Provincial Park: Longterm dune development implications. Pp. 133-142 *in* Lemieux, C.J., J.G. Nelson, T.J. Beechey and M.J. Troughton (eds.). Proceedings from the Parks Research Forum of Ontario 2003: Protected Areas and Watershed Management. Parks Research Forum of Ontario, Waterloo, ON.

Campbell, I. D. and J. H. McAndrews. 1993. Forest disequilibrium caused by rapid little Ice Age cooling. Nature 366: 336-338.

[CCIS] Canadian Climate Impacts Scenarios. Scenarios. <http://www.cics.uvic.ca/scenarios/>. Accessed September 2002.

[CCME] Canadian Council of Ministers of the Environment. 2003. Climate, Nature People: Indicators of Canada's Changing Climate. Canadian Council of Ministers of the Environment, Winnipeg, MB.

[CCAD] Canadian Conservation Areas Database. 2003. The Canadian Conservation Areas Database. Natural Resources Canada and the Canadian Council on Ecological Areas, Ottawa, ON. <http://geogratis.cgdi.gc.ca/clf/en>. Accessed November 2003.

Carter, L. 1999. Is Climate Changing Where the Wild Things Are? Acclimations – Newsletter of the US National Assessment of Climate Variability and Change 4: 9-12.

Casselman, J.M. 2002. Effects of temperature, global extremes, and climate change on year-class production of warmwater, coolwater, and coldwater fishes in the Great Lakes basin. American Fisheries Society Symposium 32: 39-60.

Casselman, J.M., D.M. Brown, J.A. Hoyle, and T.H. Eckert. 2002. Effects of climate and global warming on year-class strength and relative abundance of smallmouth bass in eastern Lake Ontario. American Fisheries Society Symposium 31: 73-90.

[CBD] Convention on Biological Diversity. 1993. Convention on Biological Diversity. United Nations. Rio de Janeiro, 5 June 1992.

COSEWIC] Committee on the Status of Endangered Wildlife in Canada. 2006. Species Assessment, Ottawa, ON. <http://www.cosewic.gc.ca/eng/sct0/original_criteria_e.cfm>. Accessed March 2006.

Crins, W.J. 2002. Ecozones, Ecoregions and Ecodistricts of Ontario. Map prepared for the ELC Working Group, Ministry of Natural Resources, Peterborough, ON.

Crins, W.J., P.A. Gray, and P.W.C. Uhlig. *In prep*. The Ecosystems of Ontario, Part I: Ecozones and Ecoregions. Ontario Ministry of Natural Resources, Peterborough, ON.

Davis, R., J. Wilkinson and D. Heaman. 2004. Fire management efforts in Ontario's protected areas: a synopsis. Pp. 421-428 *in* Lemieux, C., J.G. Nelson, T.J. Beechey and M.J. Troughton (eds.). Parks and Protected Areas Research in Ontario 2003: Protected Areas and Watershed Management. Parks Research Forum of Ontario, Waterloo, ON.

Davis, R.G. and L. McCalden. 2004. Representing Ontario's ecosystems: Ontario's approach to representing ecosystems in a system of protected areas. Ontario Ministry of Natural Resources, Peterborough, ON.

Delcourt, P.A. and H.R. Delcourt. 1987. Longer-Term Forest Dynamics of the Temperate Zone: A Case Study of Late-Quaternary Forests in Eastern North America. Springer-Verlag, New York, NY.

Ecoregions Working Group. 1989. Ecoclimatic regions of Canada, First Approximation, Ecoregions Working Group of the Canada Committee on Ecological Land Classification. Ecological Land Classification Series, No. 23, Sustainable Development Branch, Canadian Wildlife Service, Conservation and Protection, Environment Canada, Ottawa, ON. 119 pp.

Environment Canada, 1998. Adapting to Climate Variability and Change in Ontario. Volume IV of the Canada Country Study. Environment Canada, Ontario Region, Toronto, ON.

Environment Canada. 2006a. Historical Adjusted Climate Database. Meteorological Service of Canada, Ottawa, ON. <http://www.cccma.bc.ec.gc.ca/hccd/>. Accessed March 2006.

Environment Canada. 2006b. Climate Trends and Variations Bulletin for Canada. Meteorological Service of Canada – Climate Research Branch, Ottawa, ON. <http://www.msc-smc.ec.gc.ca/ccrm/bulletin/>. Accessed March 2006.

Environment Canada. 2007. Climate Trends and Variations Bulletin for Canada. Meteorological Service of Canada – Climate Research Branch, Ottawa, ON. <http://www.msc-smc.ec.gc.ca/ccrm/bulletin/>. Accessed April 2007.

[ECO] Environmental Commissioner of Ontario. 2005. 2004-2005 Annual Report: Planning Our Landscape. Environmental Commissioner of Ontario, Toronto, ON.

Flannigan, M.D. and C.E. Van Wagner. 1991. Climate change and wildfire in Canada. Canadian Journal of Forest Research 21: 66-72.

Flannigan, M.D., B.D. amiro, K.A. Logan, B.J. Stocks and B.M. Wotton. 2005. Future area burned in Canada. Climatic Change 72(1-2): 1-16.

[FPPC] Federal Provincial Parks Council. 2000. Working Together: Parks and Protected Areas in Canada. Federal Provincial Parks Council, Ottawa, ON.

Fosberg, M.A., J.G. Goldammer, D. Rind and C. Price. 1990. Global change: Effects on forest ecosystems and wildfire severity. Pp. 483-486 *in* J.G. Goldammer (ed.). Fire in the Tropical Biota: Ecosystem Processes and Global Challenges. Springer-Verlag, Berlin, Germany.

Gough, W.A. 1998. Projections of sea level change in Hudson and James Bays, Canada due to global warming. Arctic and Alpine Research 30: 84-88.

Government of Ontario. 2006. Bill 11, Provincial Parks and Conservation Reserves Act. Queen's Printer for Ontario, Toronto, ON.

Graham, R. 1988. The role of climatic change in the design of biological reserves: the paleoecological perspective for conservation biology. Conservation Biology 2: 391-394.

Gray, P.A., I. Kirkham, D. Fowle, L. White, R. Stewart, M. McLaren, K. King, J. Baker, A. Roy, D. Ogston, J. Gibb Sr., J. Lounds, R. Calvert, F. Ribordy, T. Morris, B. Davidson, M. Bohl, B.K. MacKay, C. Winter, G. Winterton, B. Rapley. 1993. Climate change. Pp. 104-106 *in* A Proposed Action Plan for 'Looking Ahead: A Wild Life Strategy for Ontario'. Prepared by the Wildlife Strategy Action Plan Ad Hoc Committee for the Minister of Natural Resources, Toronto, ON. 239pp.

Gray, P.A., D. Paleczny, R.J. Davidson, T. Beechey, B. King, S. Janetos, and S.B. Feilders. *In prep.* Ontario's protected areas: Their description and relationship to the IUCN classification system. Ontario Ministry of Natural Resources, Peterborough, ON.

Halpin, P. 1997. Global climate change and natural-area protection: management responses and research directions. Ecological Applications 7: 828-843.

Hamilton, J.P., G.S. Whitelaw and A. Fenech. 2001. Mean annual temperature and total annual precipitation trends at Canadian biosphere reserves. Environmental Monitoring and Assessment 67: 239-275.

Hannah, L., G.F. Midgley, and D. Millar. 2002. Climate change integrated conservation strategies. Global Ecology and Biogeography 11: 485-495.

Hannah, L., T.E. Lovejoy and S. Schneider. 2005. Biodiversity and climate change in context. Pp. 3-14 *in* T.E. Lovejoy and L. Hannah (eds.). Climate Change and Biodiversity, Yale University Press, New Haven, CT.

Hansen, J., Mki. Sato, R. Ruedy, K. Lo, D.W. Lea, and M. Medina-Elizade. 2006. Global temperature change. Proceedings of the National Academy of Sciences 103: 14288-14293.

Haxeltine. A. and I. Prentice. 1996. BIOME3: An equilibrium terrestrial biosphere model based on ecophysiological constraints, resources availability, and competition among plant function types. Global Biogeochemical Cycles 10: 693-709.

Hills, G.A. 1960. Regional site research. The Forestry Chronicle 36: 401-423.

Hills, G. A. 1961. The Ecological Basis for Land Use Planning. Department of Lands and Forests. Maple, ON. Research Report 46.

Holdridge, L. 1947. Determination of world plant formation from simple climatic data. Science 105: 367-368.

Hughes, L. 2000. Biological consequences of global warming: is the signal already apparent? Trends in Ecology and Evolution 15: 56-61.

[IJC] International Joint Commission. 2003. Climate Change and Water Quality in the Great Lakes Basin. International Joint Commission, Ottawa, ON. http://www.ijc.org/ijcweb-e.html>. Accessed July 2003.

[IPCC] Intergovernmental Panel on Climate Change. 1990. Climate Change: The IPCC Scientific Assessment. Cambridge University Press, Cambridge, UK.

[IPCC] Intergovernmental Panel on Climate Change. 1996. Climate Change 1995: The Science of Climate Change. Cambridge University Press, Cambridge, U.K.

[IPCC] Intergovernmental Panel on Climate Change. 2000. Special Report on Emissions Scenarios. Working Group III, Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.

[IPCC] Intergovernmental Panel on Climate Change. 2001. Summary for Policymakers, Climate Change 2001: The Science of Climate Change. Working Group I Third Assessment Report, Cambridge University Press, Cambridge, U.K.

[IPCC] Intergovernmental Panel on Climate Change. 2007. IPCC Fourth Assessment Report: Summary for Policymakers. Cambridge University Press, Cambridge, U.K.

Jones, B. and D.J. Scott. 2006. Implications of climate change for visitation to Ontario's provincial parks. Leisure 30(1): 233-261.

Lavender, B., J. V. Smith, G. Koshida, and L.D. Mortsch (eds.). 1998. Binational Great Lakes-St. Lawrence basin climate change and hydrologic scenarios report. Environment Canada, Toronto, ON.

Lemieux, C.J. 2002. Climate change and terrestrial biome distribution in Canada: Implications for protected areas policy, planning and management. University of Waterloo Master's of Environmental Studies Thesis. University of Waterloo, Waterloo, ON.

Lemieux, C.J. and D.J. Scott. 2005. Climate change, biodiversity conservation and protected areas planning in Canada. The Canadian Geographer 49 (4): 384-399.

Lemieux, C.J., T.J. Beechey and D.J. Scott. In prep. A Survey on Protected Areas and Climate Change (PACC) in Canada. Canadian Council on Ecological Areas (CCEA) Technical Report, Ottawa, ON.

Lemieux, C.J., T.J. Beechey and D.J. Scott. In prep. The Canadian Protected Areas and Climate Change (PACC) Survey. Canadian Council on Ecological Areas Technical Report, Ottawa, ON.

Lessa, P.L., J.A. Cook and J.L. Patton. 2003. Genetic footprints of demographic expansion in North America, but not Amazonia, during the Late Quaternary. Proceedings of the National Academy of Sciences 100 (18): 10331-10334.

*Liu, K.B. 1990. Hol*ocene paleoecology of the boreal forest and Great Lakes-St. Lawrence forest in northern Ontario. Ecological Monographs 60(2): 179-212.

Lofgren, B.M., F.H. Quinn, A.H. Clites, R.A. Assel, A.J. Eberhardt, and C.L. Luukkonen. 2002. Evaluation of potential impacts on Great Lakes water resources based on climate scenarios of two GCMs. Journal of Great Lakes Research 28(4): 537-554.

Lopoukhine, N. 1990. National Parks, ecological integrity and climatic change. Pp. 317-328 *in* Wall, G. and M. Sanderson (eds.). Climatic Change: Implications for Water and Ecological Resources. Symposium held in Waterloo, Ontario, March 15-16, 1990. University of Waterloo, Waterloo, ON. Department of Geography Publication Series, Occasional Paper No. 11

Lopoukhine, N. 1991. The role of Canada's National Parks in a changed climate. pp. 295-300 *in* Wall, G. (ed.). Symposium on the Impacts of Climatic Change and Variability on the Great Plains. University of Waterloo, Waterloo, ON. Department of Geography Publication Series, Occasional Paper No. 12.

Malcolm, J.R. and A. Markham. 2000. Global Warming and Terrestrial Biodiversity Decline. World Wildlife Fund International, Washington, DC.

Malcolm, J., D. Puric-Mladenovic and H. Shi. 2004. A Climate Change Atlas for 134 Forest Tree Species of Ontario, Canada. University of Toronto, Toronto, ON. http://www.forestry.utoronto.ca/treeatlas/mainpage/main_page.htm>. Accessed November 2004.

McCarty, J. 2001. Ecological consequences of recent climate change. Conservation Biology 15: 320-331.

McFarlane, N. G.J. Boer, J.P. Blanchet and M. Lazare. 1992. The CCC second generation GCM and its equilibrium climate. Journal of Climatology 5: 1013-1044.

Mortsch, L.D., H. Hengeveld, M. Lister, B. Lofgren, F. Quinn, M. Slivitzky and L. Wenger. 2000. Climate change impacts on the hydrology of the Great Lakes-St. Lawrence system. Canadian Water Resources Journal 25(2): 153-179.

Neilson, R. 1995. A model for predicting continental-scale vegetation distribution and water balance. Ecological Applications 5: 362-385.

Neilson, R. 1998. Simulated changes in vegetation distribution under global warming. Pp. 441-456 *in* R. Watson, M. Zinyowera, R. Moss (eds.). The Regional Impacts of Climate Change: An Assessment of Vulnerability - A Special Report of IPCC Working Group 2. Cambridge University Press, Cambridge, UK.

Noble, T. 1986. Ecological representation in parks (Regions 0-5E). Ontario Ministry of Natural Resources, Toronto, ON.

Obbard, M. E. and L. R. Walton. 2005. The importance of Polar Bear Provincial Park to the southern Hudson Bay population in the context of future climate change. Pp.105-115 *in* Rehbein, C.K., J. G. Nelson, T. J. Beechey and R. J. Payne (eds.). Parks and Protected Areas Research in Ontario 2002: Proceedings of the Parks Research Forum (PRFO) Annual Meeting May 2004. Parks Research Forum of Ontario (PRFO), Waterloo, ON.

Obbard, M.E., M.R.L. Cattet, T. Moody, L.R. Walton, D. Potter, J. Inglis and C. Chenier. 2006. Temporal trends in the body condition of southern Hudson Bay polar bears. Ontario Ministry of Natural Resources, Applied Research and Development Branch, Sault Ste. Marie, ON. Climate Change Research Information Note No. 3. 8 p.

[OMNR] Ontario Ministry of Natural Resources. 1977. Ontario provincial parks: A proposed policy. Division of Parks, Toronto, ON.

[OMNR] Ontario Ministry of Natural Resources. 1978. Ontario provincial parks: Planning and management policies. Division of Parks, Toronto, ON.

[OMNR] Ontario Ministry of Natural Resources. 1981. A framework for the conservation of Ontario's earth science features. Parks and Recreational Areas Branch, Toronto, ON.

[OMNR] Ontario Ministry of Natural Resources. 1986. Killarney Provincial Park Management Plan. Ontario Ministry of Natural Resources, Toronto, ON.

[OMNR] Ontario Ministry of Natural Resources. 1988. Pinery Provincial Park Resource management strategy. Ontario Ministry of Natural Resources, Peterborough, ON.

[OMNR] Ontario Ministry of Natural Resources. 1992a. Strategic plan for Ontario fisheries – SPOF II: An ecosystem approach to managing fisheries. Ontario Ministry of Natural Resources, Toronto, ON. 22 p.

[OMNR] Ontario Ministry of Natural Resources. 1992b. Ontario provincial parks – planning and management policies. Ontario Ministry of Natural Resources, Toronto, ON.

[OMNR] Ontario Ministry of Natural Resources. 1995a. Quetico Provincial Park management plan. Ontario Ministry of Natural Resources, Toronto, ON.

[OMNR] Ontario Ministry of Natural Resources. 1995b. Lake Superior Provincial Park management plan. Ontario Ministry of Natural Resources, Toronto, ON.

[OMNR] Ontario Ministry of Natural Resources. 1997. Quetico Provincial Park fire management plan. Ontario Ministry of Natural Resources, Peterborough, ON.

[OMNR] Ontario Ministry of Natural Resources. 2001. Rondeau Provincial Park vegetation management plan. Ontario Ministry of Natural Resources, Peterborough, ON.

[OMNR] Ontario Ministry of Natural Resources. 2004a. Fire management policy for provincial parks and conservation reserves. Ontario Ministry of Natural Resources, Peterborough, ON.

[OMNR] Ontario Ministry of Natural Resources. 2004b. Forest fire management strategy for Ontario. Ontario Ministry of Natural Resources, Aviation, Flood and Fire Management Branch, Toronto, ON.

[OMNR] Ontario Ministry of Natural Resources. 2006. Climate change and MNR: A [Draft] strategy and action plan. Ontario Ministry of Natural Resources, Climate Change Program, Peterborough, ON.

Ontario Wildlife Working Group. 1991. Climate change. Pp. 56-59 *in* Looking Ahead: A Wild Life Strategy for Ontario. A Report Prepared by the Ontario Wildlife Working Group for the Minister of Natural Resources. Toronto, ON. 172 p.

Parks Branch. 1967. Classification of Provincial Parks. Parks Branch, Toronto, ON.

Parks Canada. 1997. State of the National Parks Report. Minister of Canadian Heritage, Ottawa, ON.

[PCIC] Pacific Climate Impacts Consortium. 2006. PCIC Scenario Access Interface. Pacific Climate Impacts Consortium, Victoria, BC. http://www.pacificclimate.org/>. Accessed September 2006.

Peng, C. 2000. From static biogeographical model to dynamic global vegetation model: a global perspective on modelling vegetation dynamics. Ecological Modelling 135: 33-54.

Peters, R. 1992. Conservation of biological diversity in the face of climate change. Pp. 277-293 *in* R.L. Peters, T.E. Lovejoy (eds.). Global Warming and Biological Diversity. Yale University Press, London, UK.

Peters, R. and J. Darling. 1985. The greenhouse effect and nature reserves. Bioscience 11: 707-716.

Peters, R. and T. Lovejoy. 1992. Global Warming and Biological Diversity. Yale University Press, London, UK.

Pittock, A.B. 2006. Are scientists underestimating climate change? EOS 87(34): 340-341.

Prentice I.C. and T. Webb. 1998. BIOME 6000: reconstructing global mid-Holocene vegetation patterns from palaeoecological records. Journal of Biogeography 25: 997-1005.

Province of British Columbia. 2002. Indicators of Climate Change, 2002. Ministry of Water, Land and Air Protection, Water, Air and Climate Change Branch, Victoria, BC.

Rizzo, B. and E. Wiken. 1992. Assessing the sensitivity of Canada's ecosystems to climatic change. Climatic Change 21: 37-55.

Rowe, S. 1989. National Parks and Climate Change: Notes for a talk given to Canadian Parks Service personnel in Ottawa. Occasional Paper No. 4, National Parks Branch, Canadian Parks Service. Environment Canada, Ottawa, ON.

[SCBD] Secretariat of the Convention on Biological Diversity. 2003. Interlinkages Between Biological Diversity and Climate Change. Secretariat of the Convention on Biological Diversity, n.p.

Scott, D.J. and C.J. Lemieux. 2005. Climate change and protected areas planning in Canada. The Forestry Chronicle. 81(5): 696-703.

Scott, D.J. and C.J. Lemieux. 2007. Climate change and protected areas policy, planning and management in Canada's boreal forest. The Forestry Chronicle (in press).

Scott, D.J. and R. Suffling. 2000. Climate change and Canada's National Parks. Environment Canada, Toronto, ON.

Scott, D.J., J. Malcolm and C.J. Lemieux. 2002. Climate change and modelled biome representation in Canada's national park system: implications for system planning and park mandates. Global Ecology and Biogeography 11: 475-484.

Spittlehouse, D.L. and R.B. Stewart. 2003. Adaptation to climate change in forest management. BC Journal of Ecosystems and Management 4(1): 1-11.

Stirling, I., N.J. Lunn and J. Iacozza. 1999. Long-term trends in the population ecology of polar bears in western Hudson Bay. Arctic 52: 294-306.

Stocks, B.J. 1993. Global warming and forest fires in Canada. The Forestry Chronicle 69: 290-293.

Stocks, B.J., M.A. Fosberg, T.J. Lynham, L. Means, B.M. Wotton, Q. Yang. 1998. Climate change and forest fire potential in Russian and Canadian boreal forests. Climatic Change 38: 1-13.

Stocks, B.J. M.A. Fosberg, M.B. Wotton, T.J. Lynham and K.C. Ryan. 2000. Climate change and forest fire activity in North American boreal forests. Pp. 368-376 *in* Kasischke, E.S. and B.J. Stocks (eds.). 2000. Fire, Climate Change, and Carbon Cycling in the Boreal Forest. Springer, New York, NY.

Tallis J. 1990. Climate Change and Plant Communities. Academic Press, London, UK.

Taylor, M.E., P.A. Gray and K. Schiefer. 2006. Helping Canadians adapt to climate change in the Great Lakes coastal zone. Great Lakes Geographer 13(1): 14-25.

Thomas, C.D., A. Cameron, R.E. Green, M. Bakkenes, L.J. Beaumont, Y.C. Collingham, B.F.N. Erasmus, M.F. de Siqueira, A. Grainger, L.Hannah, L. Hughes, B. Huntley, A.S. van Jaarsveld, G.F. Midgley, L. Miles, M.A. Ortega-Huerta, A.T. Peterson, O.L. Phillips and S.E. Williams. 2004. Extinction risk from climate change. Nature 427: 145-148.

[VEMAP] Vegetation/Ecosystem Modelling and Analysis Project Members. 1995. Vegetation/Ecosystem Modelling and Analysis Project (VEMAP): Comparing biogeography and biogeochemistry models in a continental-scale study of terrestrial ecosystem responses to climate change and CO_2 doubling. Global Biogeochemical Cycles 9(4): 407-437.

Vincent, L. A. 1998. A technique for the identification of inhomogeneities in Canadian temperature series. Journal of Climate. 11: 1094–1104.

Vincent, L. A. and Gullett, D. W. 1999. Canadian historical and homogeneous temperature datasets for climate change analyses. International Journal of Climatology. 19: 1375-1388.

Vincent, L.A., X. Zhang, B.R. Bonsal, W.D. Hogg. 2002. Homogenization of daily temperatures over Canada. Journal of Climate (15): 1322-1334.

Vinnikov, K.Y., A. Robock, R.J. Stouffer, J.E. Walsh, C.C.L. Parkinson, D.J. Cavalieri, J.F.B. Mitchell, D. Garrett, and V.F. Zakharov. 1999. Global warming and northern hemispheric ice extent. Science 286: 1934-1937.

Wall, G. 1985. Climatic change and its impact on ontario tourism and recreation. Department of Geography, University of Waterloo, Waterloo, ON.

Weber, M.G. and M.D. Flannigan. 1997. Canadian boreal forest ecosystem structure and function in a changing climate: impact on fire regimes. Environmental Reviews 5: 145-166.

Welch, D. 2005. What should protected area managers do in the face of climate change? The George Wright Forum 22 (1): 75-93.

Williams, J.W. 2002. Variations in tree cover in North America since the last glacial maximum. Global and Planetary Change 35: 1-23.

Woodward, F. 1987. Climate and Plant Distribution. Cambridge University Press, Cambridge, UK.

Woodward, F.I. and D.J. Beerling. 1997. The dynamics of vegetation change: health warnings for equilibrium 'dodo' models. Global Ecology and Biogeography Letters. 6: 413-418.

Wotton, B.M. and M.D. Flannigan. 1993. Length of the fire season in a changing climate. The Forestry Chronicle 69: 187-192.

Wotton, M., K. Logan, and R. McAlpine. 2005. Climate change and the future fire environment in Ontario: Fire occurrence and fire management impacts in Ontario under a changing climate. Ontario Ministry of Natural Resources, Applied Research and Development Branch, Sault Ste. Marie, ON. Climate Change Research Report CCRR-01. 23 p.

WWF (World Wildlife Fund). 2003. Buying time: A user's manual for building resistance and resilience to climate change in natural systems. World Wildlife Fund International, Washington, DC.

Zimov, S.A., S.P. Davidov, G.M. Zimova, A.I. Davidova, F.S. Chapin III, M.C. Chapin and J.F. Reynolds. 1999. Contribution of disturbance to increasing seasonal amplitude of atmospheric CO_2. Science 284: 1973-1976.

Appendix 1: Historical Climate Variability and Trends in Ontario Provincial Parks

Rondeau Provincial Park

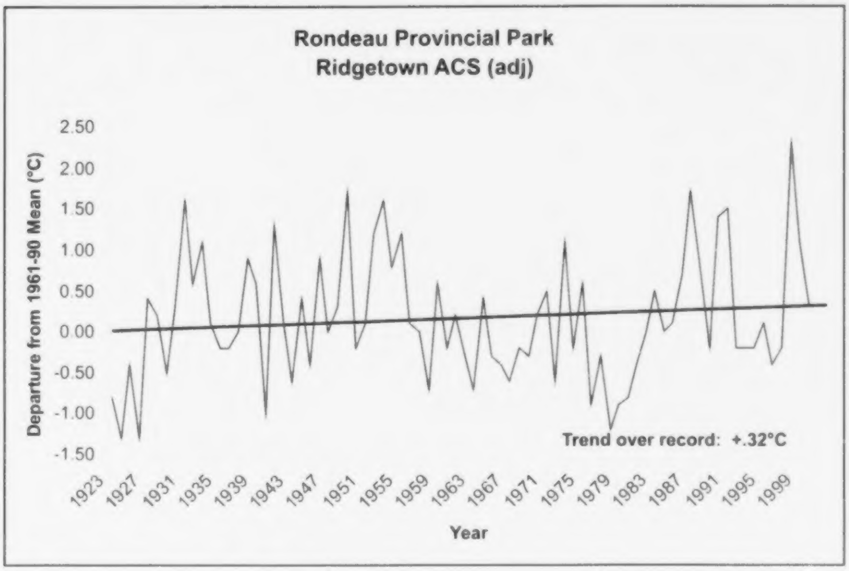

Figure 1.1 Historical temperature variability and trend in Rondeau Provincial Park, 1923-2002.

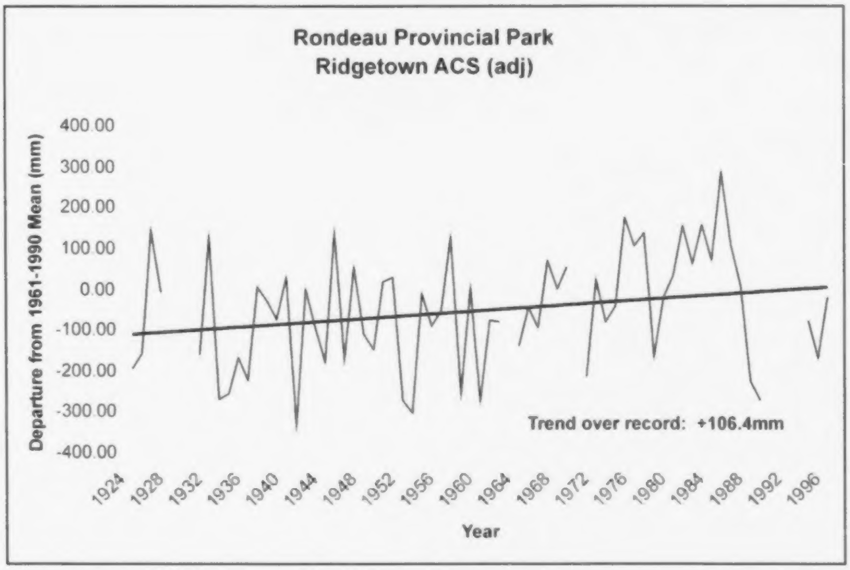

Figure 1.2 Historical precipitation variability and trend in Rondeau Provincial Park, 1924-1996.

Algonquin Provincial Park

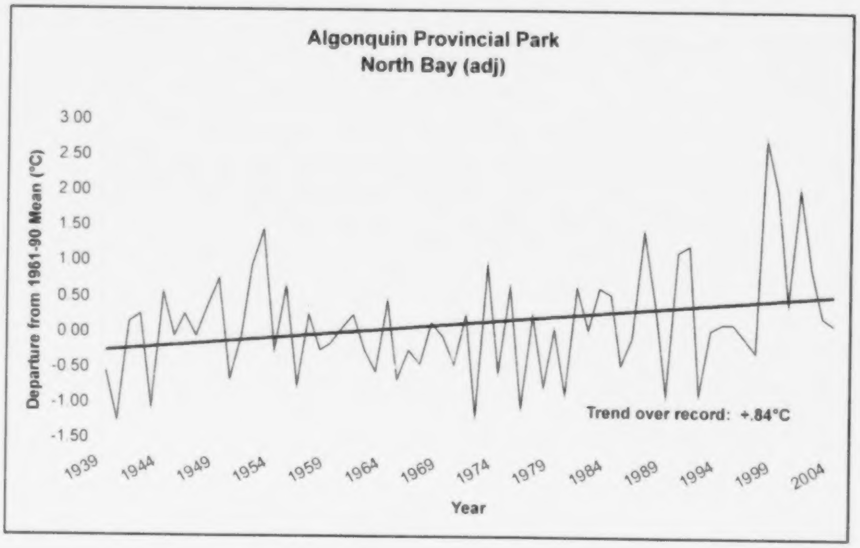

Figure 1.3 Historical temperature variability and trend in Algonquin Provincial Park, 1939-2004.

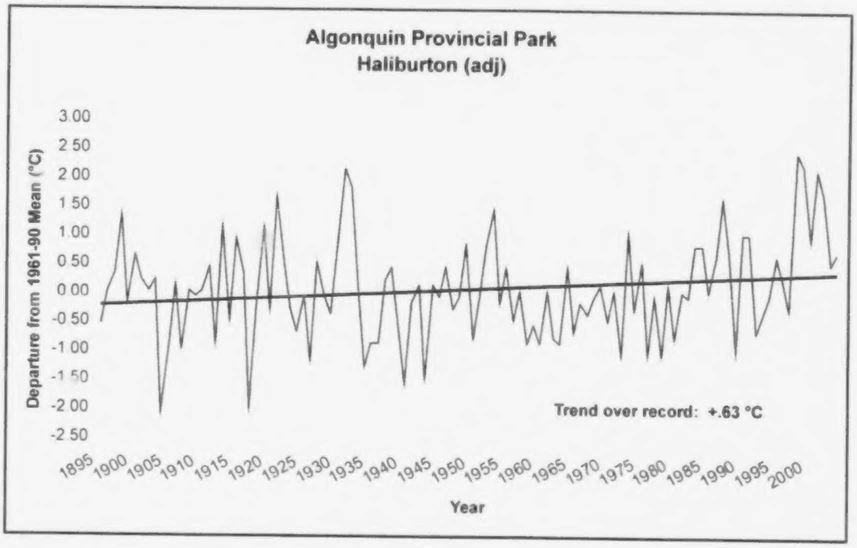

Figure 1.4 Historical temperature variability and trend in Algonquin Provincial Park, 1895-2004.

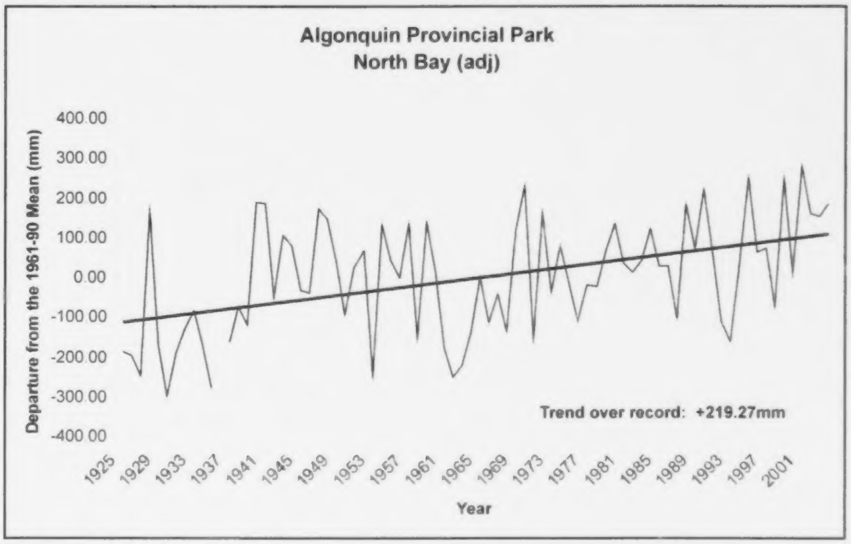

Figure 1.5 Historical precipitation variability and trend in Algonquin Provincial Park, 1925-2004.

Lady Evelyn-Smoothwater Provincial Park

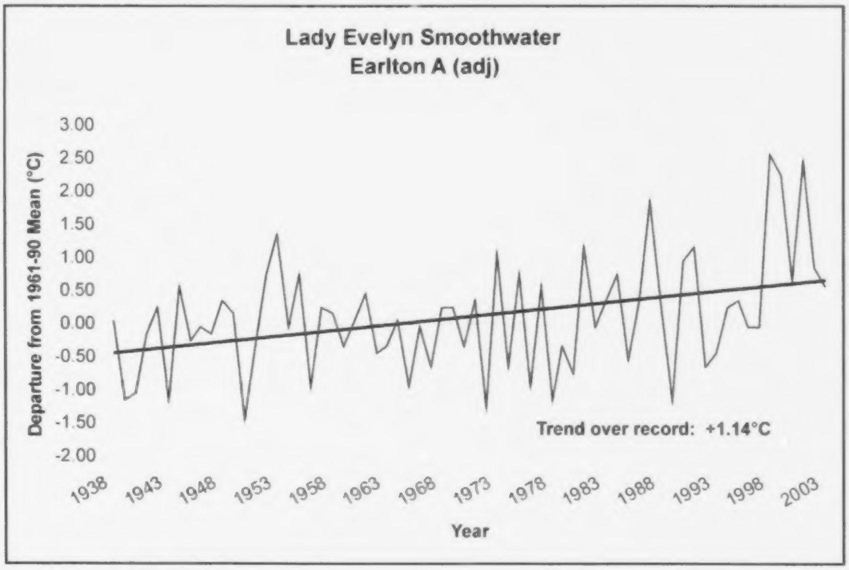

Figure 1.6 Historical temperature variability and trend in Lady-Evelyn Smoothwater Provincial Park, 1938-2003.

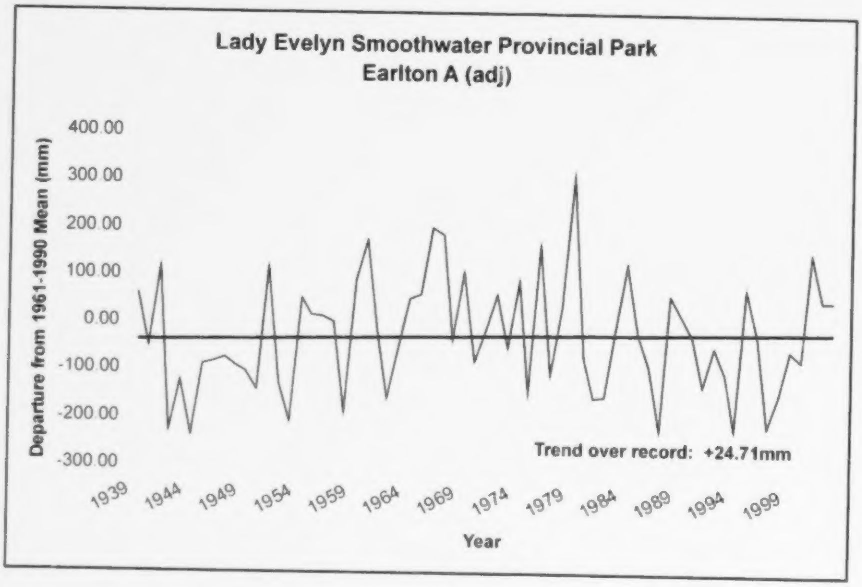

Figure 1.7 Historical precipitation variability and trend in Lady-Evelyn Smoothwater Provincial Park, 1939-2003.

Sandbanks Provincial Park

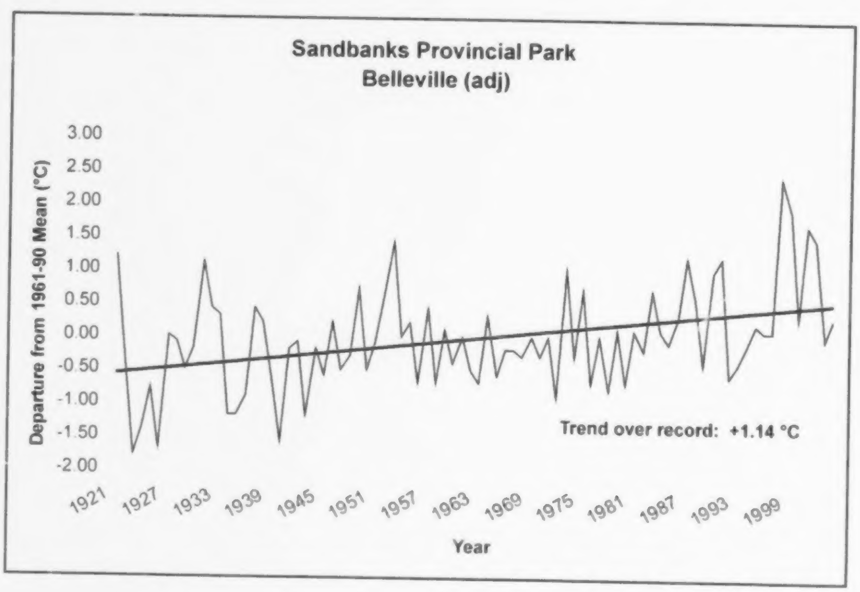

Figure 1.8 Historical temperature variability and trend in Sandbanks Provincial Park, 1921-2004.

Quetico Provincial Park

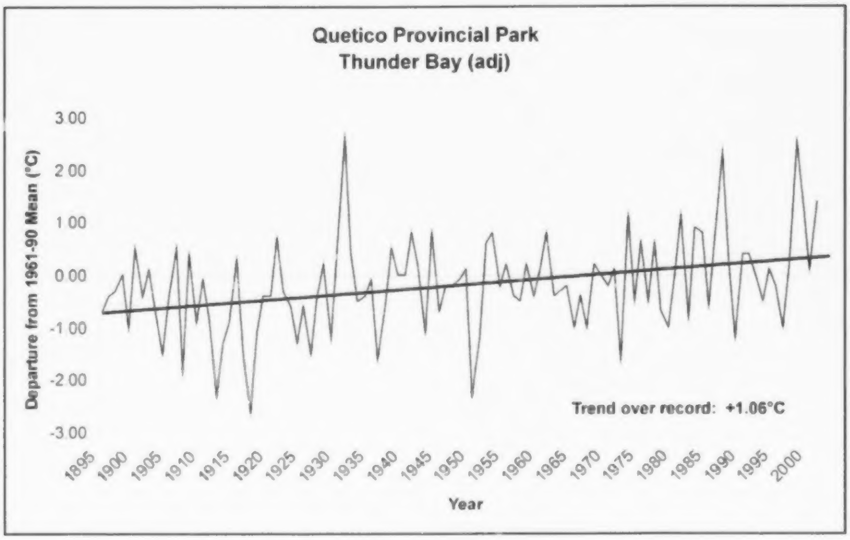

Figure 1.9 Historical temperature variability and trend in Quetico Provincial Park, 1895-2004.

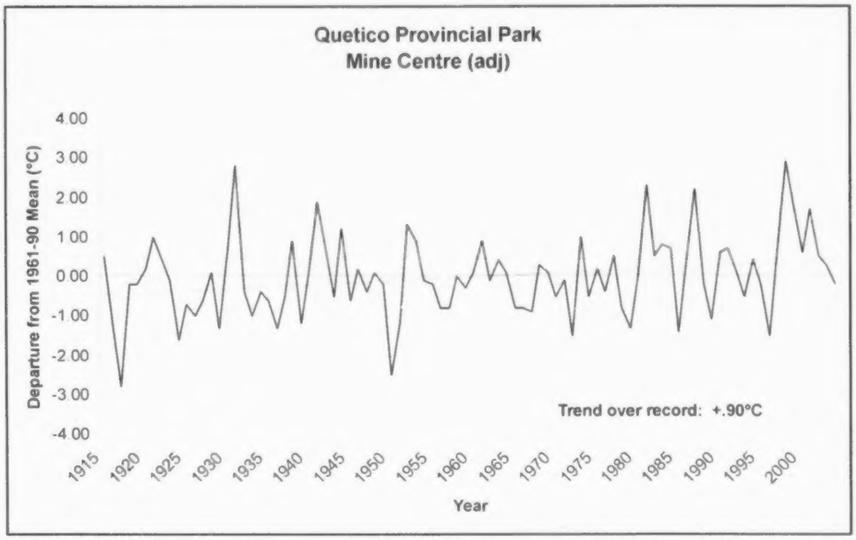

Figure 1.10 Historical temperature variability and trend in Quetico Provincial Park, 1915-2003.

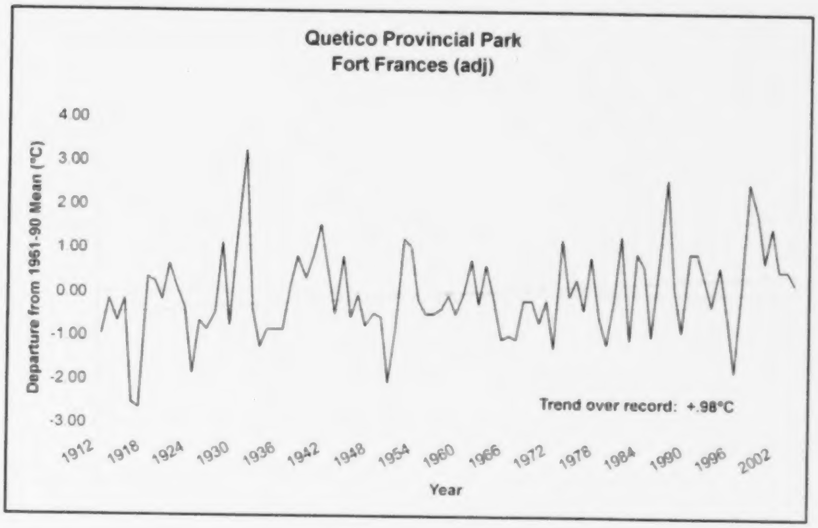

Figure 1.11 Historical temperature variability and trend in Quetico Provincial Park, 1912-2003.

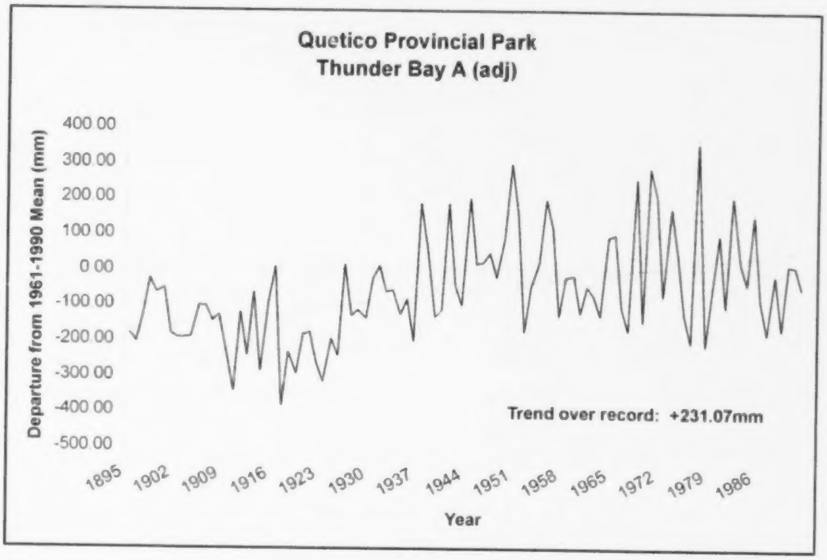

Figure 1.12 Historical precipitation variability and trend in Quetico Provincial Park, 1895-1992.

Wabakimi Provincial Park

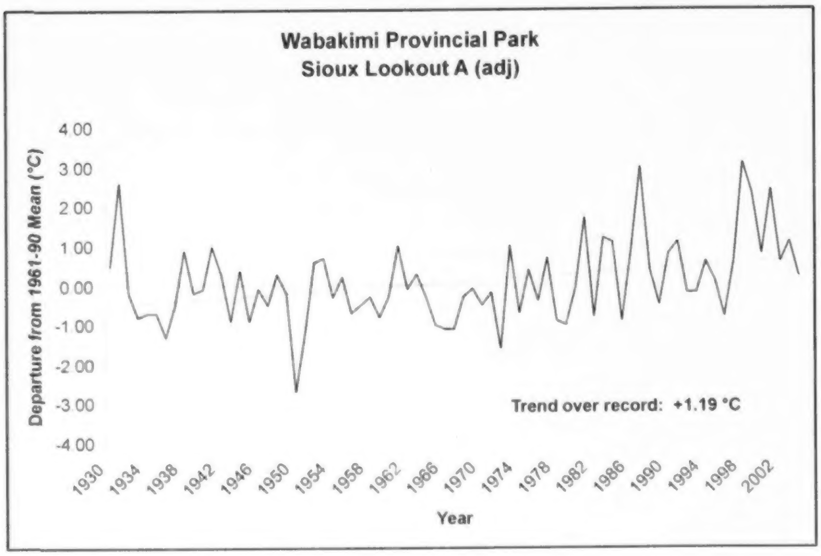

Figure 1.13 Historical temperature variability and trend in Wabakimi Provincial Park, 1930-2004.

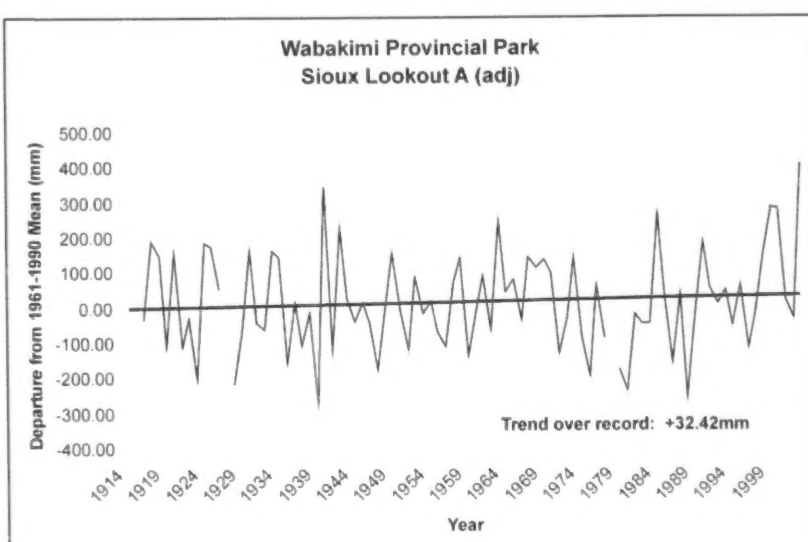

Figure 1.14 Historical precipitation variability and trend in Wabakimi Provincial Park, 1914-2004.

Lake Superior Provincial Park

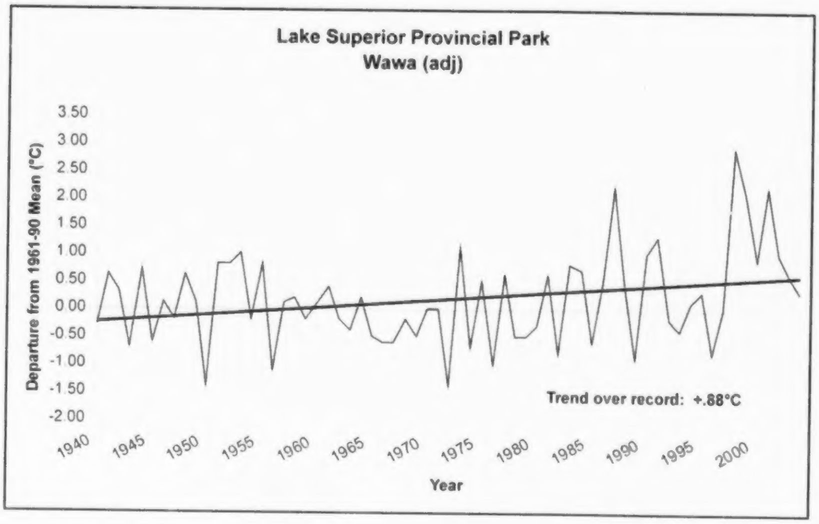

Figure 1.15 Historical temperature variability and trend in Lake Superior Provincial Park, 1940-2004.

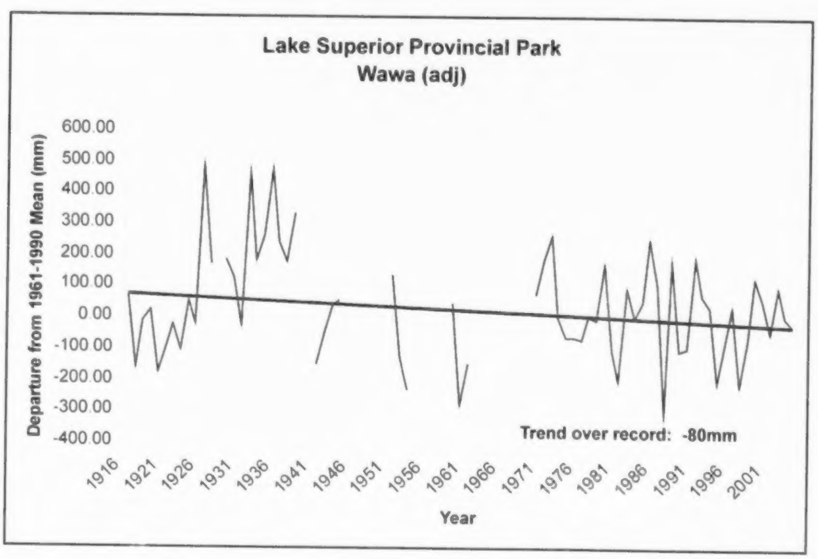

Figure 1.16 Historical precipitation variability and trend in Lake Superior Provincial Park, 1916-2004.

Tidewater Provincial Park

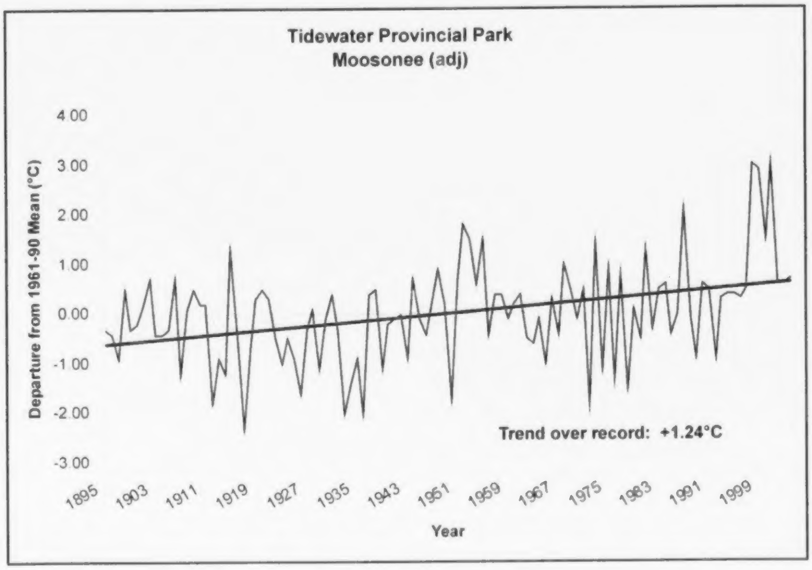

Figure 1.17 Historical temperature variability and trend in Tidewater Provincial Park, 1895-2004.

Appendix 2: Summary of SRES (Special Report on Emission Scenarios) Scenarios

Many climate models and scenarios that depict different types of human behaviour in the twenty-first century are available. For example, expected changes in global mean temperature associated with each of six marker scenarios documented by the Intergovernmental Panel on Climate Change (IPCC 2001) are illustrated in Fig. 2 of Step 2 of this report. These scenarios are summarized below. For more information about models and scenarios, readers should consult the original document.

A1FI, A1T and A1B

The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes include convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family is organized into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B; where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).

A2

The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in a continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

B1

The B1 storyline and scenario family describes a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

B2

The B2 storyline and scenario family describes a world in which the emphasis is on local solutions and economic, social, and environmental sustainability are promoted. It is a world with a continuously increasing global population (at a rate lower than A2), intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

Appendix 3: Special Report on Emmission Scenario (SRES) General Circulation Model (GCM) Scatterplots for Each Provincial Park Analyzed

General circulation model (GCM) acronym summary:

CGCM2 – Canada General Circulation Model, Second Generation
CSIRO – Australian Commonwealth Scientific and Industrial Research Organization
HadCM3 – Hadley Centre Coupled Model, Version 3 (United Kingdom)
CCSM – Community Climate System Model (USA)
GFDL – Geophysical Fluid Dynamics Laboratory (USA)
NCAR – National Center for Atmospheric Research (USA)

Rondeau Provincial Park

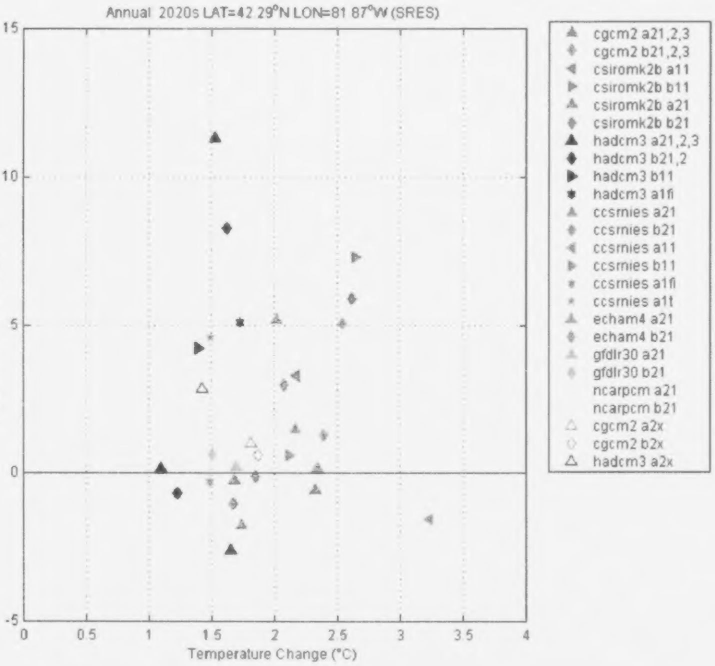

Figure 3.1 Precipitation (%) and temperature change (°C) SRES GCM scatterplot for Rondeau Provincial Park ~2020s.

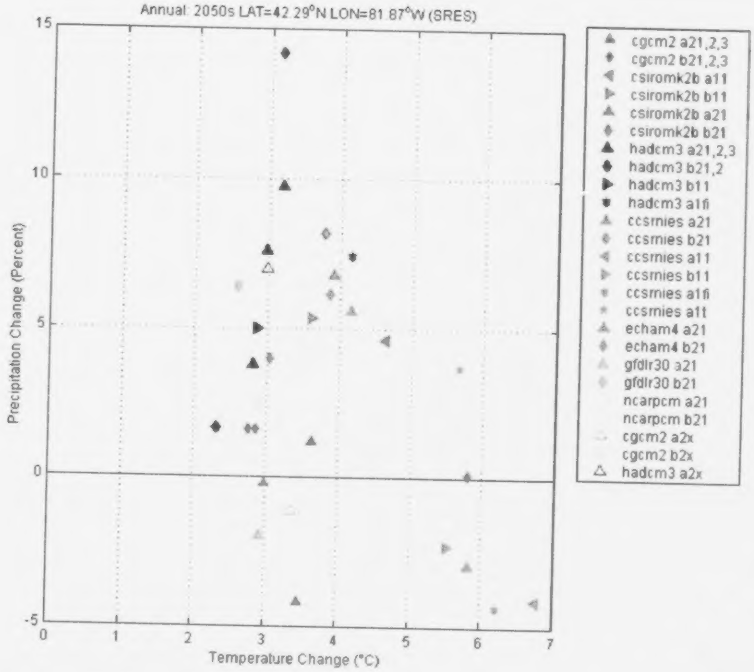

Figure 3.2 Precipitation (%) and temperature change (°C) SRES GCM scatterplot for Rondeau Provincial Park ~2050s.

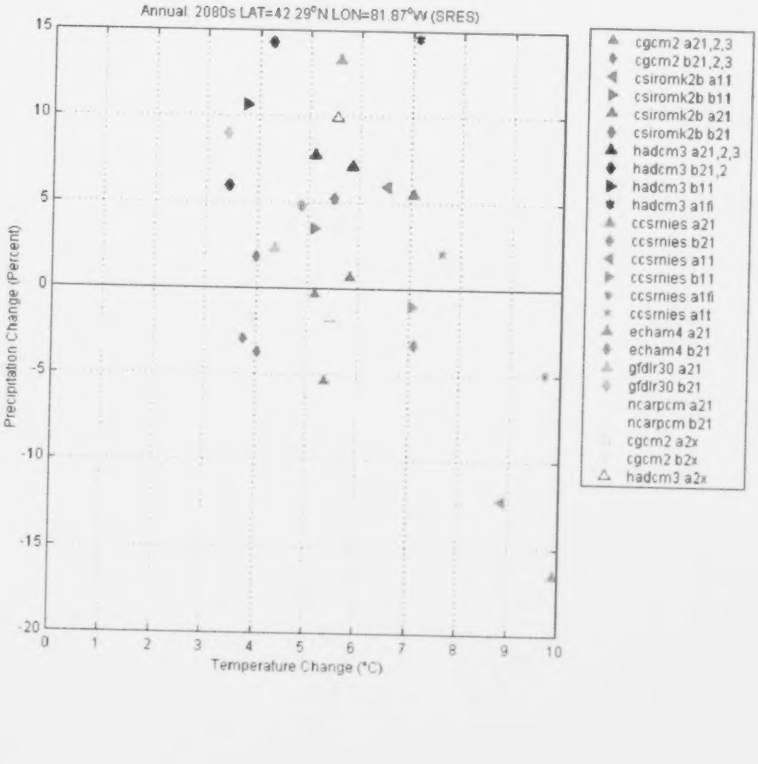

Figure 3.3 Precipitation (%) and temperature change (°C) SRES GCM scatterplot for Rondeau Provincial Park ~2080s.

Algonquin Provincial Park (Algonquin Zone)

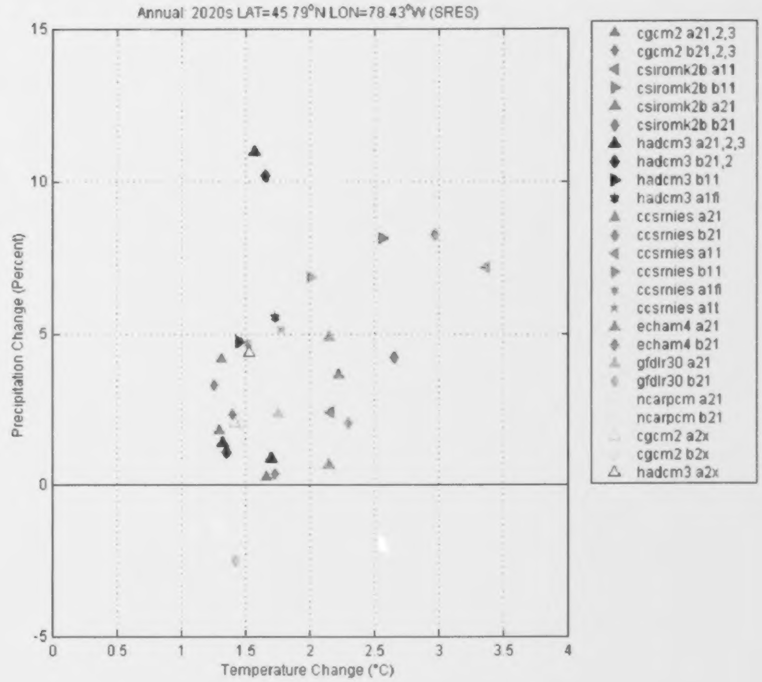

Figure 3.4 Precipitation (%) and temperature change (°C) SRES GCM scatterplot for Algonquin Provincial Park ~2020s.

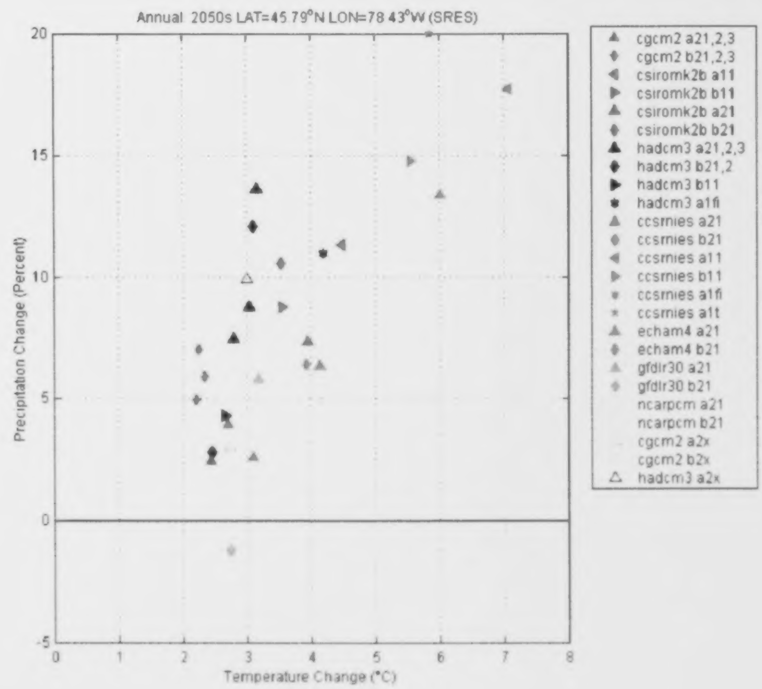

Figure 3.5 Precipitation (%) and temperature change (°C) SRES GCM scatterplot for Algonquin Provincial Park ~2050s.

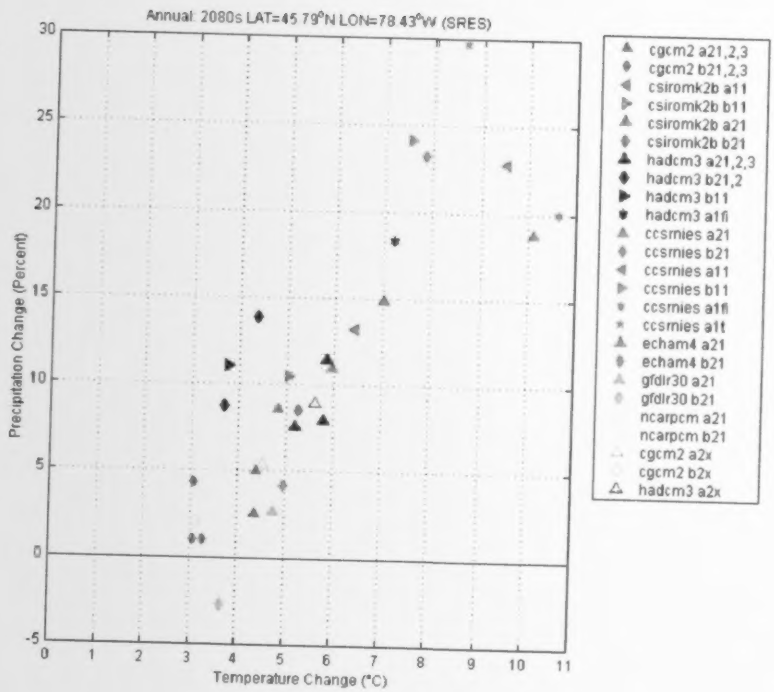

Figure 3.6 Precipitation (%) and temperature change (°C) SRES GCM scatterplot for Algonquin Provincial Park ~2080s.

Lady Evelyn-Smoothwater Provincial Park (Northeast Zone)

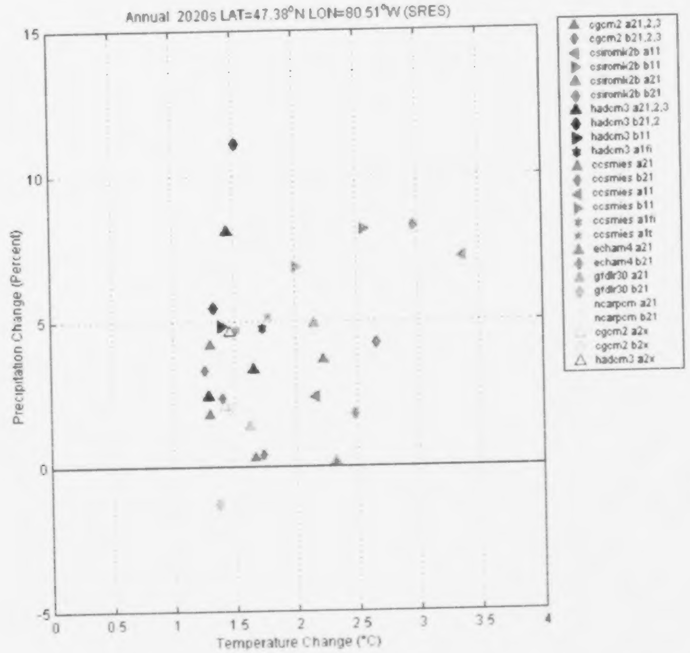

Figure 3.7 Precipitation (%) and temperature change (°C) SRES GCM scatterplot for Lady Evelyn-Smoothwater Provincial Park ~2020s.

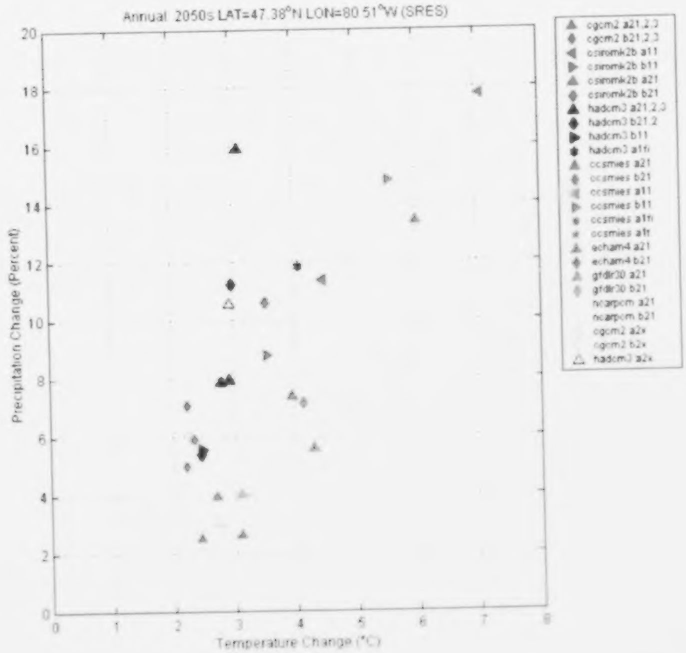

Figure 3.8 Precipitation (%) and temperature change (°C) SRES GCM scatterplot for Lady Evelyn-Smoothwater Provincial Park ~2050s.

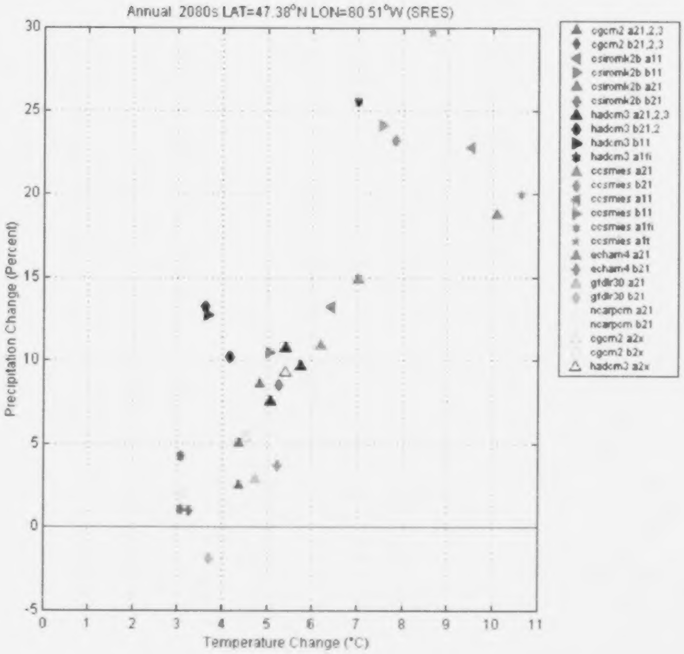

Figure 3.9 Precipitation (%) and temperature change (°C) SRES GCM scatterplot for Lady Evelyn-Smoothwater Provincial Park ~2080s.

Sandbanks Provincial Park (Southeast Zone)

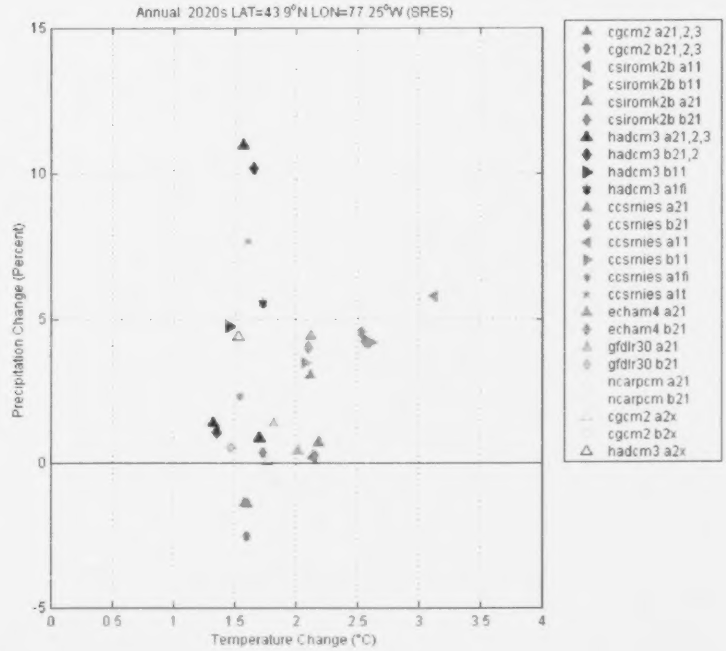

Figure 3.10 Precipitation (%) and temperature change (°C) SRES GCM scatterplot for Sandbanks Provincial Park ~2020s.

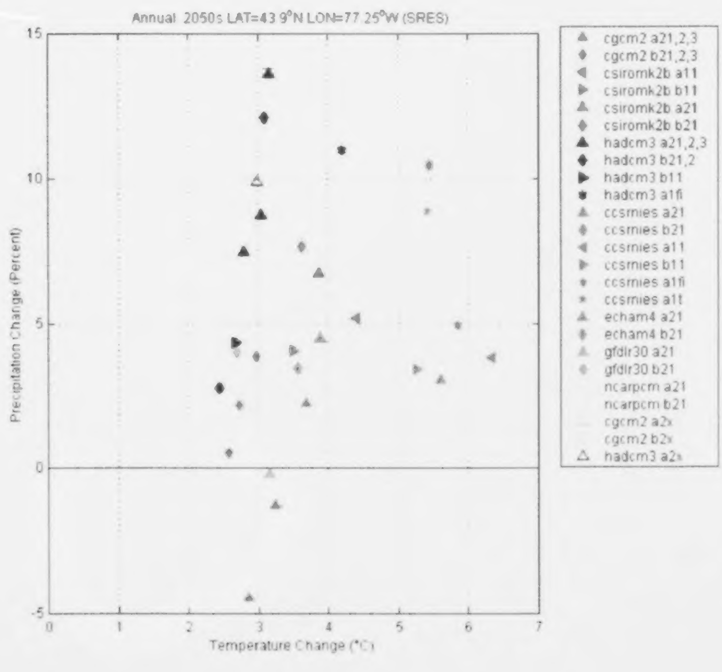

Figure 3.11. Precipitation (%) and temperature change (°C) SRES GCM scatterplot for Sandbanks Provincial Park ~2050s.

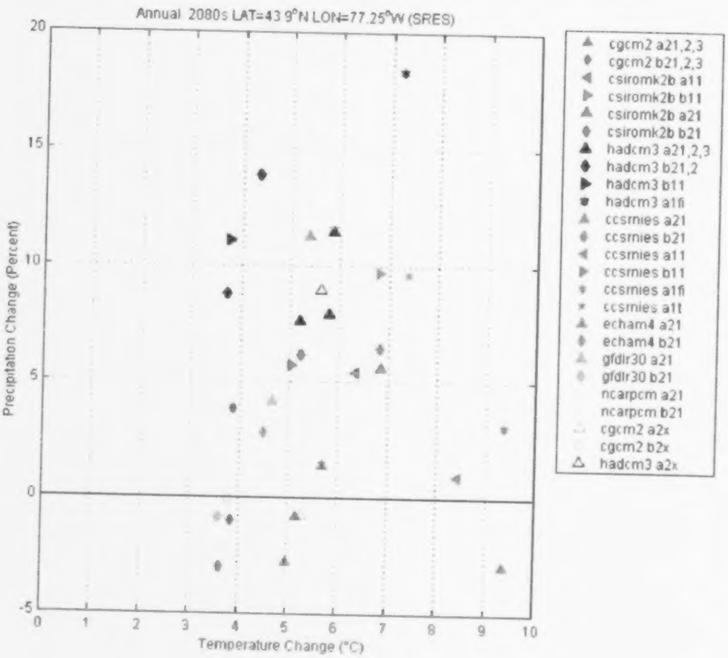

Figure 3.12 Precipitation (%) and temperature change (°C) SRES GCM scatterplot for Sandbanks Provincial Park ~2080s.

Quetico Provincial Park (Northwest Zone)

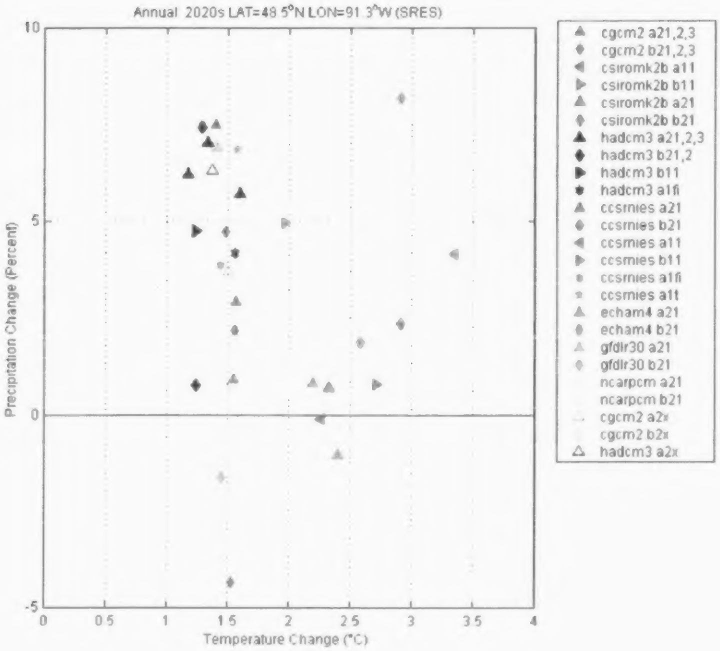

Figure 3.13 Precipitation (%) and temperature change (°C) SRES GCM scatterplot for Quetico Provincial Park ~2020s.

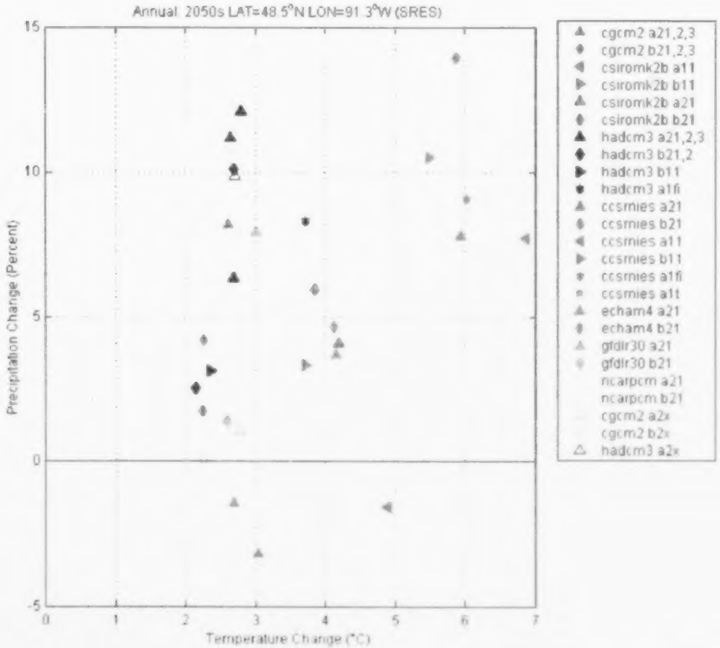

Figure 3.14 Precipitation (%) and temperature change (°C) SRES GCM scatterplot for Quetico Provincial Park ~2050s.

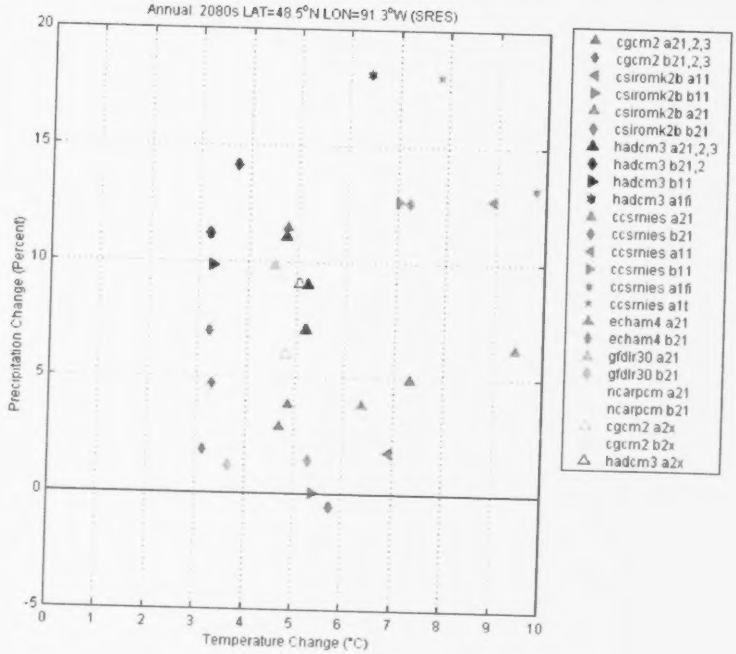

Figure 3.15 Precipitation (%) and temperature change (°C) SRES GCM scatterplot for Quetico Provincial Park ~2080s.

Wabakimi Provincial Park (Northwest Zone)

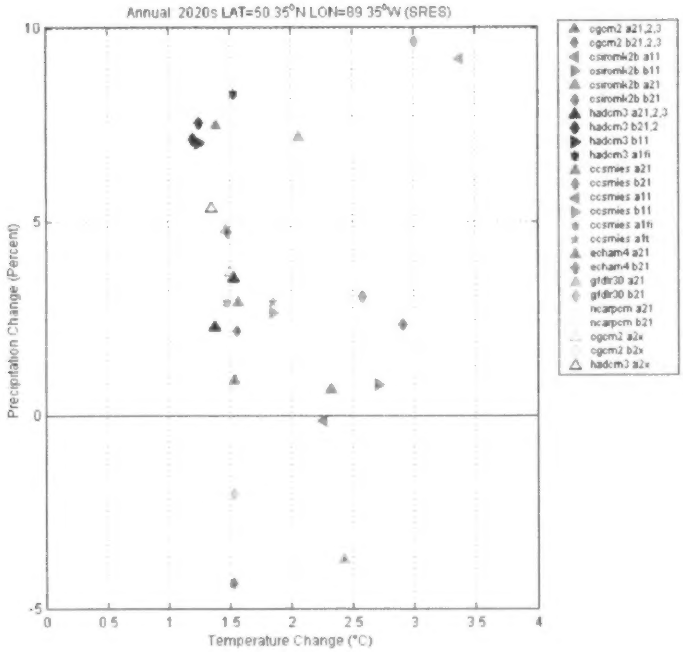

Figure 3.16 Precipitation (%) and temperature change (°C) SRES GCM scatterplot for Wabakimi Provincial Park ~2020s.

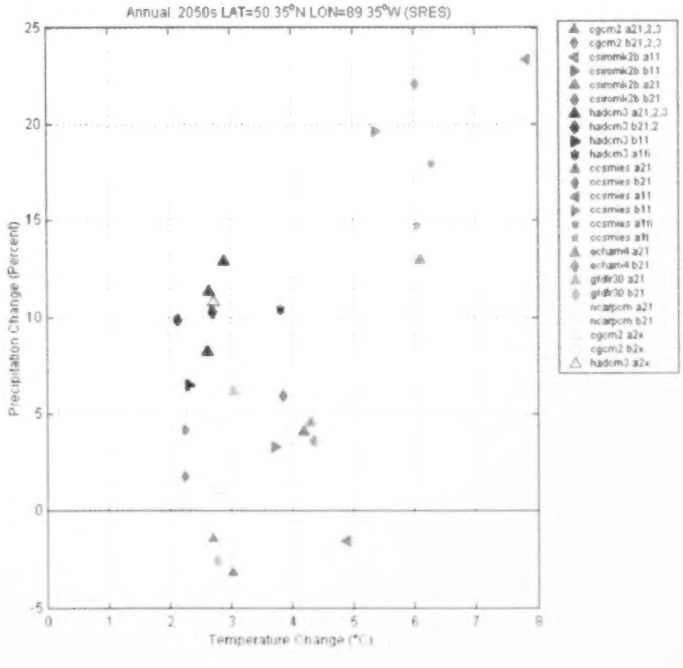

Figure 3.17 Precipitation (%) and temperature change (°C) SRES GCM scatterplot for Wabakimi Provincial Park ~2050s.

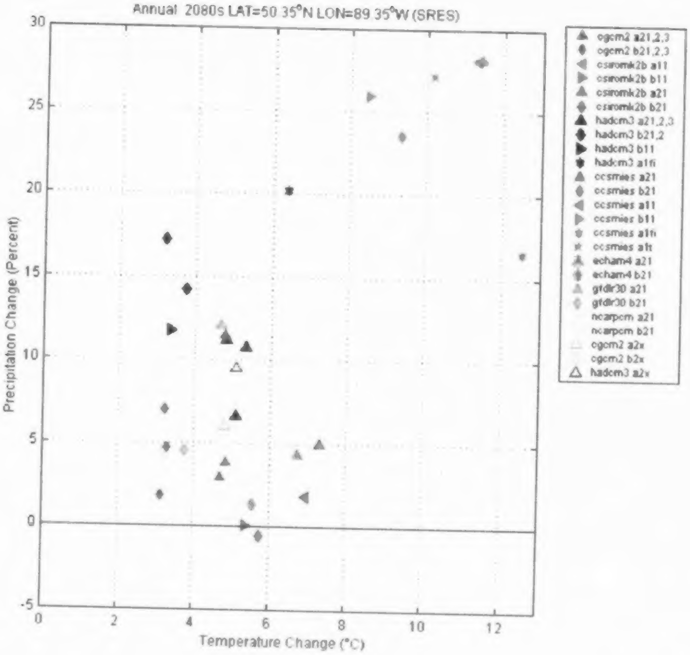

Figure 3.18 Precipitation (%) and temperature change (°C) SRES GCM scatterplot for Wabakimi Provincial Park ~2080s.

Lake Superior Provincial Park (Northeast Zone)

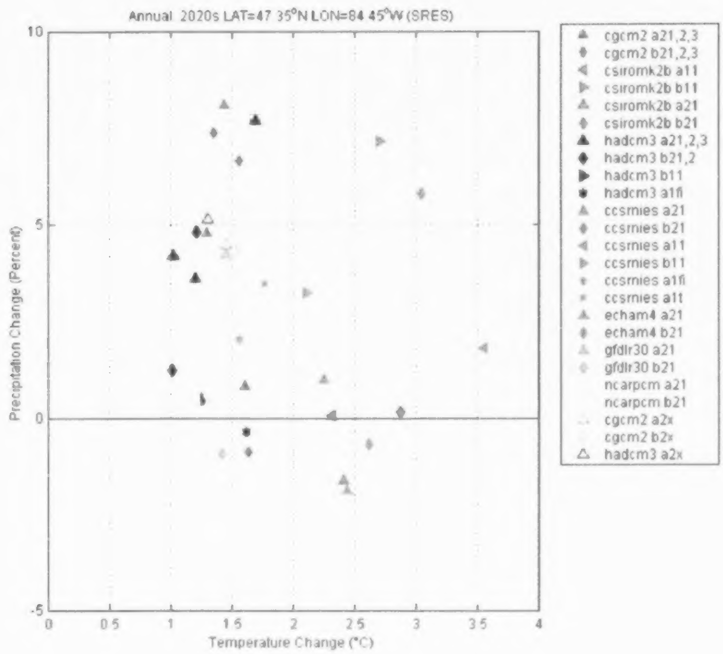

Figure 3.19 Precipitation (%) and temperature change (°C) SRES GCM scatterplot for Lake Superior Provincial Park ~2020s.

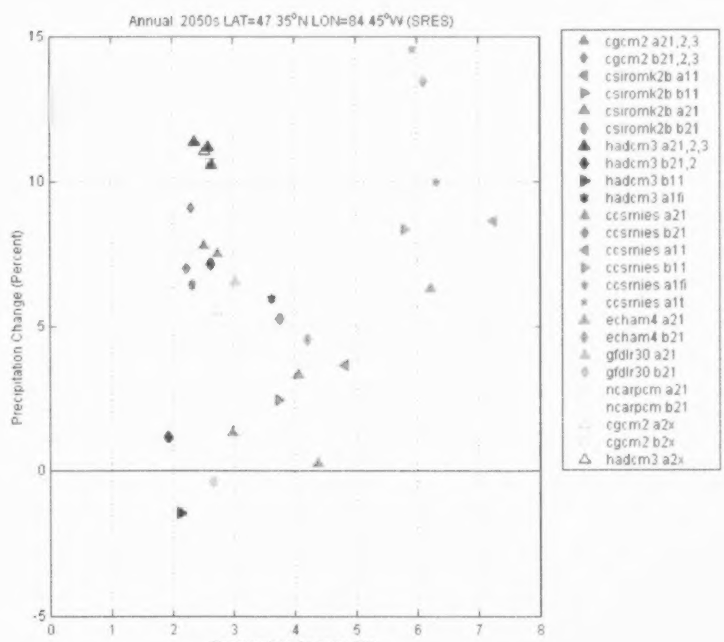

Figure 3.20 Precipitation (%) and temperature change (°C) SRES GCM scatterplot for Lake Superior Provincial Park ~2050s.

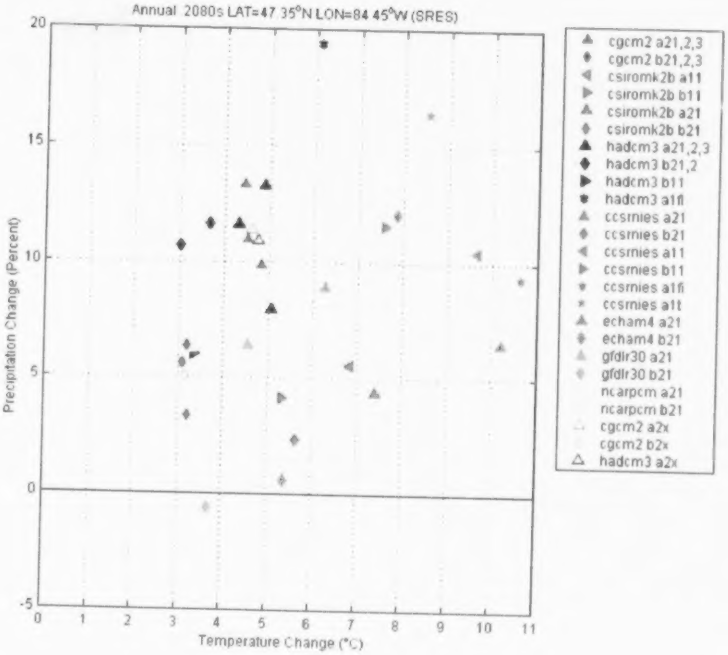

Figure 3.21 Precipitation (%) and temperature change (°C) SRES GCM scatterplot for Lake Superior Provincial Park ~2080s.

Tidewater Provincial Park (Northeast Zone)

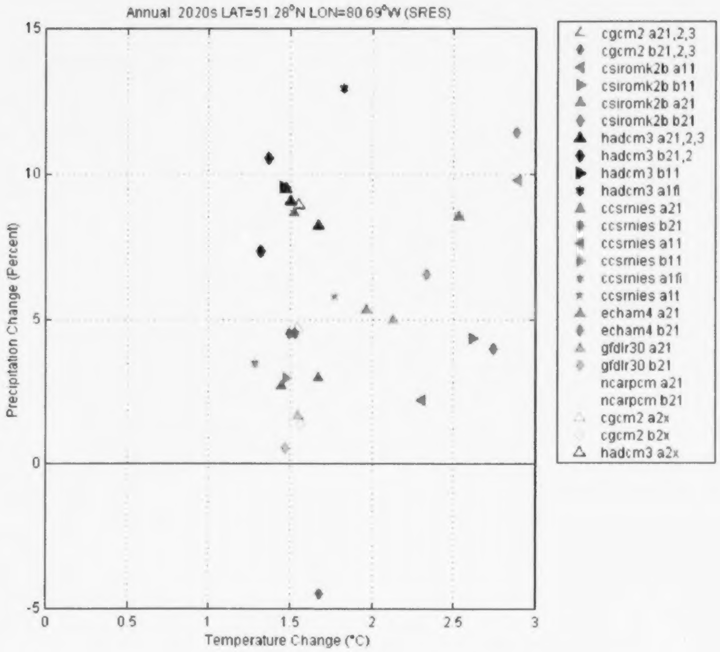

Figure 3.22 Precipitation (%) and temperature change (°C) SRES GCM scatterplot for Tidewater Provincial Park ~2020s.

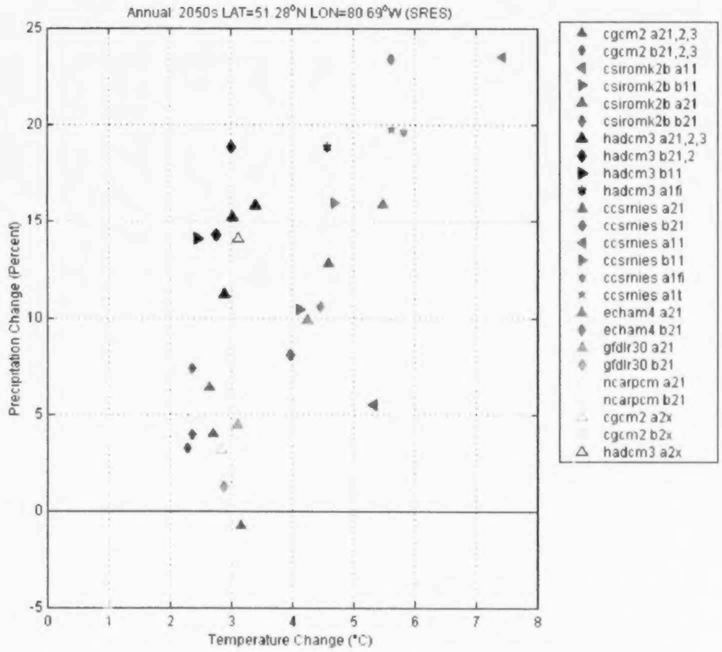

Figure 3.23 Precipitation (%) and temperature change (°C) SRES GCM scatterplot for Tidewater Provincial Park ~2050s.

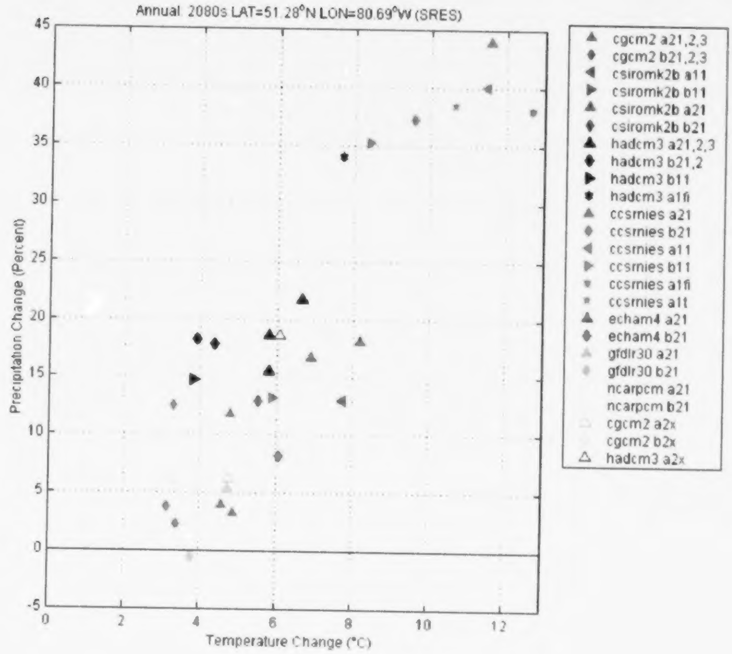

Figure 3.24 Precipitation (%) and temperature change (°C) SRES GCM scatterplot for Tidewater Provincial Park ~2080s.

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(0.3k P.R. 07 04 20)
ISBN 978-1-4249-3394-5 (print)
ISBN 978-1-4249-3395-2 (PDF)